Recovery of Macroalgae Following Widespread Sea Urchin Mortality With a Description of the Nearshore Hard-Bottom Habitat on the Atlantic Coast of Nova Scotia

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RECOVERY OF MACROALGAE FOLLOWING WIDESPREAD SEA URCHIN MORTALITY WITH A DESCRIPTION OF THE NEARSHORE HARD-BOTTOM HABITAT ON THE ATLANTIC COAST OF NOVA SCOTIA

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ABSTRACT

Moore, D.S. and R.J. Miller. 1983. Recovery of macroalgae following widespread sea urchin mortality with a description of the nearshore hard-bottom habitat on the Atlantic coast of Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1230: vii + 94 p.

A survey of 2,900 km of the Atlantic coastline of Nova Scotia including 81 transects and 1,044 stations was conducted in 1982. This survey measured the area released to macroalgae by recent sea urchin (Strongylocentrotus droebachiensis) mass mortalities, characterized the physical habitat of this area, and contrasted the seaweed recovery to areas where sea urchins still remained. This habitat is of interest to fishery biologists and ecologists because it supports an important lobster (Homarus americanus) fishery and has a large potential for macroalgal production.

Within the survey area, 1,400 km of shoreline was bordered by habitat suitable for sea urchins and macroalgae. Of this, sea urchin mortality in 1980 and 1981 was nearly complete along 872 km of shore to the maximum survey depth of 15 m. The area of this habitat was 227 km^2. The remaining 528 km of shore bordered by 284 km^2 of habitat to 15 m depth was still populated by sea urchins in 1982.

The survey area had a convoluted shore with a 11:1 ratio of shoreline length to straight-line distance and a considerable range of exposures to wave action. Although only 26% of the shoreline length was on the open coast, 82% of the sea urchin and macroalgal habitat bordered these exposed shores.

On transects where sea urchins were absent for one year the percentage algal cover over five arbitrary classifications of wave exposure was two to 14 times higher than on transects with sea urchins. Each of four kelp species, Irish moss (a short red algae), and a grouping of filamentous species occurred at a higher fraction of stations without sea urchins than with sea urchins. Only Agarum cribrosum, a kelp low on the sea urchin's grazing preference, was not more common in the absence of sea urchins. Generally, macroalgae expanded to deeper and more sheltered locations in the absence of sea urchins, but had not yet recovered to the mature beds seen in other parts of Nova Scotia that had been without sea urchins for many years.

Key words: Sea urchin, mass mortality, algal communities, recolonization, exposure index, juvenile lobster, Nova Scotia, kelp beds.

RÉSUMÉ

Moore, D.S. and R.J. Miller. 1983. Recovery of macroalgae following widespread sea urchin mortality with a description of the nearshore hard-bottom habitat on the Atlantic coast of Nova Scotia. Can. Tech. Rep. Fish. Aquat. Sci. 1230: vii + 94 p.

Un relevé de 2,900 km de la côte atlantique de la Nouvelle-Ecosse, comprenant 81 transects et 1,044 stations, a été effectué en 1982. Au cours de ce relevé, on a mesuré la superficie remise à la disposition des macro-algues par les récentes mortalités massives de l'oursin commun (Strongylocentrotus droebachiensis), on a caractérisé l'habitat physique de cette zone et comparé les zones de rétablissement des algues avec celles encore occupées par les oursins. Ce

genre d'habitat intéresse les halieutistes et les écologistes car il supporte une importante pêcherie de homards (Homarus americanus) et offre un bon potentiel de production de macro-algues.

Dans la zone du relevé, 1,400 km de ligne de côte contenaient un habitat convenable pour les oursins et les macro-algues. La mortalité des oursins dans cette zone en 1980 et 1981 avait été presque totale sur 872 km, du rivage à la profondeur étudiée de 15 m. La superficie de cette zone était de 227 km^2. Les 528 km de rivage restant, bordés par 284 km^2 d'habitat jusqu'à 15 m de profondeur, étaient encore peuplés d'oursins en 1982.

La zone étudiée possède un rivage sinueux, avec rapport longueur de rivage/distance en ligne droite de 11:1 et un large éventail d'expositions à l'action des vagues. Bien que seulement 26% de la ligne de rivage soient exposés, 82% de l'habitat des oursins et des macro-algues bordent ces rivages exposés.

Sur les transects d'où les oursins avaient été absents pendant un an, le pourcentage de couverture algale dans cinq groupes d'exposition à l'action des vagues, arbitrairement définis, était de 14 fois plus grand que sur les transects où il y avait des oursins. Chacune des quatre espèces de varechs, mousse d'Irlande (une algue rouge courte) et un groupement d'espèces filamenteuses, se rencontraient à une plus forte proportion de stations sans oursins qu'aux stations avec oursins. Seul Agarum cribrosum, au varech peu apprécié des

oursins, ne montrait pas d'augmentation aux endroits où les oursins étaient absents. En général, les macro-algues s'étaient propagés dans les endroits plus profonds et mieux abrités là où il n'y avait pas d'oursins, mais ne s'étaient pas encore rétablies au niveau des lits n tures d'autres parties de la Nouvelle-Ecosse dépourvues d'oursins depuis plusieurs années.

INTRODUCTION

Typically, either the green sea urchin (Strongylocentrotus droebachiensis) or seaweed (fleshy attached macroalgae) exerts dominance of the rocky subtidal habitat on the south coast of Nova Scotia. Breen and Mann (1976) and Chapman (1981) observed a progressive decrease in the seaweed cover in St. Margaret's Bay [see Fig. 1 (foldouts in the back cover) for place names] from about 90% to about 10% of the suitable habitat. Observations of sea urchin grazing on kelp and the renewed dominance of kelps within a few months after experimental removal of sea urchins from five plots were convincing evidence that the sea urchin was the direct cause of the seaweed's disappearance (Breen and Mann, 1976; Chapman, 1981). Wharton and Mann (1981) surveyed seven sites at 10 m depth, spanning 450 km (straight-line distance) of Nova Scotia's southern coast. At each site they found abundant sea urchins and, seaweed cover of only 10% to 20%, mostly species unpalatable to sea urchins.

In the autumns of 1980 and 1981 the sea urchin population suffered mass mortality that was nearly complete along 160 km of shore and totalled over 80,000 t live weight. Mortalities were intermittent along another 280 km (Miller and Colodey, 1983).

This nearshore hard-bottom habitat is of interest to fisheries biologists and ecologists because it supports a lobster fishery and has a large potential for seaweed primary production (Mann, 1972b; Gerard and Mann, 1979). Chapman (1981) demonstrated that macroalgal production in mature beds is about 100 times benthic microalgal production in the absence of macroalgae.

The purposes of this study were: 1) to measure the area of habitat released to seaweeds by sea urchin mortalities; 2) to obtain measures of seaweed recovery; 3) to observe seaweed occurrence in areas with sea urchins for comparison with areas without sea urchins; and 4) to correlate seaweed occurrence with depth and exposure to wave action. Fortuitously, the spread of sea urchin mortalities was observed in the autumn of 1982 during the survey for the above data.

In the summer and autumn of 1982 scuba divers occupied 1,044 stations on 81 transects over hard bottom. This represented a shoreline length of 1,400 km. An additional 1,500 km of shoreline bordered by soft bottom (mud, sand, gravel) was identified but not surveyed.

MATERIALS AND METHODS

SHORELINE MEASUREMENTS

Shoreline lengths at chart datum were measured with a digitizer (HP9874A), programmed for use as a planimeter, from the following Canadian Hydrographic Service charts:

Chart Name	Number	Scale
Charles Island to Osbourne Head	4347	1:58,500
Osbourne Head to Betty Island	4385	1:36,480
Bedford Basin	4310	1:12,000
St. Margaret's Bay	4386	1:39,416
Mahone Bay	4381	1:38,909
Pearl Island to Cape LaHave	4384	1:39,023
Cape LaHave to Liverpool Bay	4211	1:37,500
Western Head to Little Hope Island	4212	1:37,500
Port Hebert to Lockeport	4213	1:37,500
Lockeport Harbour to Cape Negro	4214	1:37,500
Cape Negro to Cape Sable	4215	1:37,500

Between Ship Harbour and Medway Harbour (Fig. 1 - foldouts), hydrographic charts were used to judge if shore was suitable habitat for algae and/or urchins. Suitable habitat was ultimately defined as a minimum of 50% cover by hard bottom for a minimum 10 m width subtidally, i.e. including bedrock, boulder, and cobble and excluding mud, sand, and gravel.

Length of suitable shoreline was measured at chart datum from Ship Harbour to Medway Harbour and transects located at 16 km intervals except for a 70 km length of shoreline between Sambro and Peggy's Cove where they were spaced at 10 km intervals. To avoid bias in location of marks, mainland shoreline was always measured within a five-minute square of latitude and longitude, then islands within the square were measured beginning and ending with the southern tip, before moving on to the next square. During field surveys of the transects we found that some sandy shore had not been excluded, so the final estimate of suitable shoreline length was reduced accordingly.

Before measuring the shoreline from Medway Harbour to Cape Sable Island the area was surveyed from an outboard runabout and, where necessary, the bottom was viewed through a glass-bottomed bucket. This permitted a more exact exclusion of unsuitable habitat than from using only the hydrographic charts. Transects were then located every 16 km of suitable shoreline as in the initial phase of the survey.

TRANSECT SURVEYS

Disposable transect lines were prepared in the laboratory by spooling polished cotton "butcher's twine," marked at 10 m intervals with waterproof ink, on squid jig reels. Using an electric drill to turn the axel of the reel, two people could prepare a reel with 1,300 m of transect line in 30 minutes.

Transect data forms were photocopied onto waterproof paper. Data recorded on the forms were:

1) The time divers entered and left the water.

2) Distance in 10's of meters from the start of the transect.

3) Depth in feet at each observation station, taken from a diver's depth gauge. The gauge was calibrated using a marked line from the surface. Depths were later corrected to chart datum using a tide table and then converted to meters.

4) Substrate type classed in one or more of the following categories (e.g. 3/6 = scattered boulders on sand):

1) bedrock	5) gravel (<4 cm)
2) dense boulders	6) sand
3) scattered boulders	7) mud
4) cobble (<20 cm)	

5) Percentage plant cover estimated visually as the amount of rock bottom not visible due to seaweed. Although no measurement technique was used, the three divers who recorded data during the survey were intercalibrated several times on their estimates of percent cover.

6) Algae observed were recorded in decreasing order of abundance at each station. The following algal groupings were used: filamentous algae, moss (Chondrus crispus and Phyllophora sp.), Laminaria longicruris; Laminaria digitata, Saccorhiza dermatodea, Alaria esculenta, and Agarum cribrosum. The last five species are all large kelps.

7) Sea urchin density was estimated visually as being within ranges of <1, 1 to 10, 10 to 100, or >100 per square meter. Divers calibrated their visual estimates by counting the numbers of sea urchins in several 0.25 m^2 quadrats. Sea urchins smaller than about 5 mm test diameter were not included in the estimate.

The authors chose to make visual approximations of algal cover and sea urchin densities rather than more precise quantitative sampling from quadrats in order to acquire data from large numbers of transects and stations. The great length of shoreline surveyed would have been sparsely sampled indeed, had more quantitative methods been chosen.

Transects ran perpendicular to the shore from the points selected using the digitizer. They ran to a depth of 15 m below chart datum or to where the substratum became greater than 50% gravel, sand, or mud - whichever came first. Although seaweed, especially A. cribrosum, does occur deeper, this depth range was considered to encompass well over 90% of the algal biomass (Mann, 1972a; Edelstein et al., 1969; Sharp et al., 1981) and primary production. Large areas of rock bottom with low sea urchin densities probably exist below 15 m, but the competition with macrophytes for substratum quickly disappears with depth.

Local inshore fishing vessels (8 m to 13 m) were hired to transport divers to the transect sites. After locating the starting point of a transect the vessel was moved directly offshore to where the transect was estimated to end, and anchored. The ending point was estimated using the boat's sounder and the captain's knowledge of substrate type found in the area.

Two divers were then transported to shore in a small skiff. After entering the water the diver carrying the transect line located the start of the transect, defined as the bottom of the Fucus/Ascophyllum zone, typically located about 0.5 m above chart datum. Here the free end of the transect line was tied to a rock or a firmly attached piece of vegetation, and a compass course was set to the fishing vessel anchored offshore. Both divers then proceeded offshore, the first laying out the transect line and the second recording observations at 10 m intervals.

For transects between 200 m and 500 m (length estimated prior to entering the water), the diver recording observations made at least five observations at 10 m intervals at the beginning, middle, and end of the transect. Transect line was laid out for the entire transect in these cases. For transects over 500 m long, divers entered the water at the beginning, middle, and end and took five or more observations each place. The total length of these transects was estimated using the radar on the fishing vessel.

In a few cases the substrate changed from suitable to unsuitable repeatedly, or turned to sand at shallow depths. Here a diver was towed by the skiff to a depth of 15 m while estimating the percentage of suitable substrate and percentage of plant cover.

HELICOPTER SURVEYS

On November 25 and 26, 1982, exposed beaches were surveyed from a helicopter for accumulations of dead sea urchins. Although this method is less quantitative than observations by diving, it is far faster and was conducted later in the fall after the spread of mortalities was expected to have stopped because of low temperatures. Dead sea urchins accumulate near the high tide line, and accumulations greater than 1/m of beach were considered indicative of abnormal (e.g. disease induced) mortality. Methods are given in more detail in Miller and Colodey (1983).

EXPOSURE

A major factor influencing sea urchin and macrophyte distribution and abundance is exposure to waves (Dalby et al., 1978; Jones and Demetropoulos, 1968). Wave influence is difficult to quantify and it was thought practical to develop only a crude scale of exposure to wave forces.

The open Atlantic coastline of Nova Scotia is exposed to near maximum wave force when compared with other coastlines throughout the world. The wave climate of the open Atlantic Ocean determines these wave forces (Hans Neu, pers. comm.). It is therefore feasible to develop a scale based on the influence the open Atlantic Ocean wave climate has on a site and, for sheltered locations, exposure to locally generated waves.

The following wave exposure index was developed as a means of getting exposure rankings for our study sites.

1) Sheltered - In a bay completely protected from the open ocean and with less than a 20° angle open to a 8 km or more fetch within the bay.

2) - In a bay with a 1° to 20° angle open to the ocean or completely protected from the ocean with a 20° to 45° angle open to a 8 km or more fetch within the bay.

3) - In a bay with a 21° to 40° angle open to the ocean or with a 1° to 20° angle open to ocean and greater than a 45° angle open to a 8 km or more fetch within the bay.

4) - On the open coastline with less than a 90° angle open to the ocean.

5) Exposed - On the open coastline with greater than a 90° angle open to the ocean.

The angle and distance measurements were taken at the point a transect met the shore. This scale does not have extremely sheltered classes because these areas are not suitable for subtidal seaweeds and sea urchins.

HABITAT FOR SMALL JUVENILE LOBSTERS

A review of the literature on substrate type preferred by juvenile lobsters (Homarus americanus) revealed that quantitative field studies are lacking. Botera and Atema (1982) found that, in the laboratory, the preferred substrate for settling of Stage IV larvae was a "rock garden." The rock garden was composed of rocks of 8 cm to 10 cm in diameter piled on sand. They also found that a smaller but significant number chose mud. Pottle and Elner (1982) reported similar findings; the Stage VII to Stage X juveniles preferred gravel to dredge spoils (mud). Cooper and Uzmann (1977) reported that in the field they found Stage IV to Stage X lobsters mostly in mud substrates next to solid substrates, but gave no data.

Based on the above two laboratory studies we have defined juvenile lobster habitat as boulders on cobble, gravel, sand, or mud, cobble alone, or cobble on gravel, sand, or mud. We lack measurements of area of mixed hard and soft bottom where the

soft bottom was more than 50% cover. Thus, the measure of juvenile lobster habitat given is the fraction of the habitat suitable for sea urchins and seaweed. The scarcity of field data identifying juvenile lobster habitat also limits the accuracy of measurements.

RESULTS

SHORELINE LENGTH

A total of 2,900 km of shoreline was included in the survey of which 1,400 km was suitable hard bottom (Table 1). Approximately 872 km of the suitable shoreline was within the area of nearly complete urchin die off in 1980 and 1981 as described by Miller and Colodey (1983).

As shown in Figure 1 (foldouts), most of the unsuitable shoreline (1,494 km) occurred in estuarine areas; the major ones, proceeding from east to west, were:

1) Ship Harbour
2) Jeddore Harbour
3) Musquodoboit Harbour
4) Petpeswick Inlet
5) Chezzetcook Inlet
6) Western Shore Mahone Bay
7) LaHave River
8) Medway Harbour
9) Port Joli
10) Port Hebert
11) Sable River
12) Lockeport Harbour
13) Negro Harbour
14) Barrington Bay

The ratio of total shoreline length to the straight-line distance for the survey area was 11:1.

TRANSECT DESCRIPTIONS

Profiles of each of the 81 transects are represented in Figure 2. The profiles show depth, distance from shore, substrate type, and macrophyte taxa found at each observation site on the transect. This detail is presented to permit comparisons of plant community structure in future years.

HABITAT AREA AND EXPOSURE

Transect lengths and ending depths were correlated with exposure (Fig. 3); with r values of 0.42 and 0.55 respectively ($P<0.01$). Transects in the most exposed sites were on average an order of magnitude longer (644 m vs 56 m) and ended more than twice as deep (12.6 m vs 5.2 m) as those in the most sheltered sites (Table 1).

The length of shoreline of each exposure class (l_e) was the product of the proportion of the number of transects in each exposure class (t_e/T) and the total shoreline length of suitable habitat (L), i.e.:

Table 1. Shoreline lengths, transect lengths, transect ending depths, and areas of hard bottom.

	Number of transects	Shoreline length (km)	Mean transect length (m)	Area (km^2)	Mean transect depth (m)
Areas without sea urchins	50	872	260	227	-
Areas with sea urchins	31	528	537	284	-
Exposure 1	15	259	56	15	5.2
2	10	173	172	30	6.0
3	13	225	203	46	9.3
4	15	259	427	111	9.8
5	28	484	640	310	12.6
Totals:	81	1,400	366	512	9.4

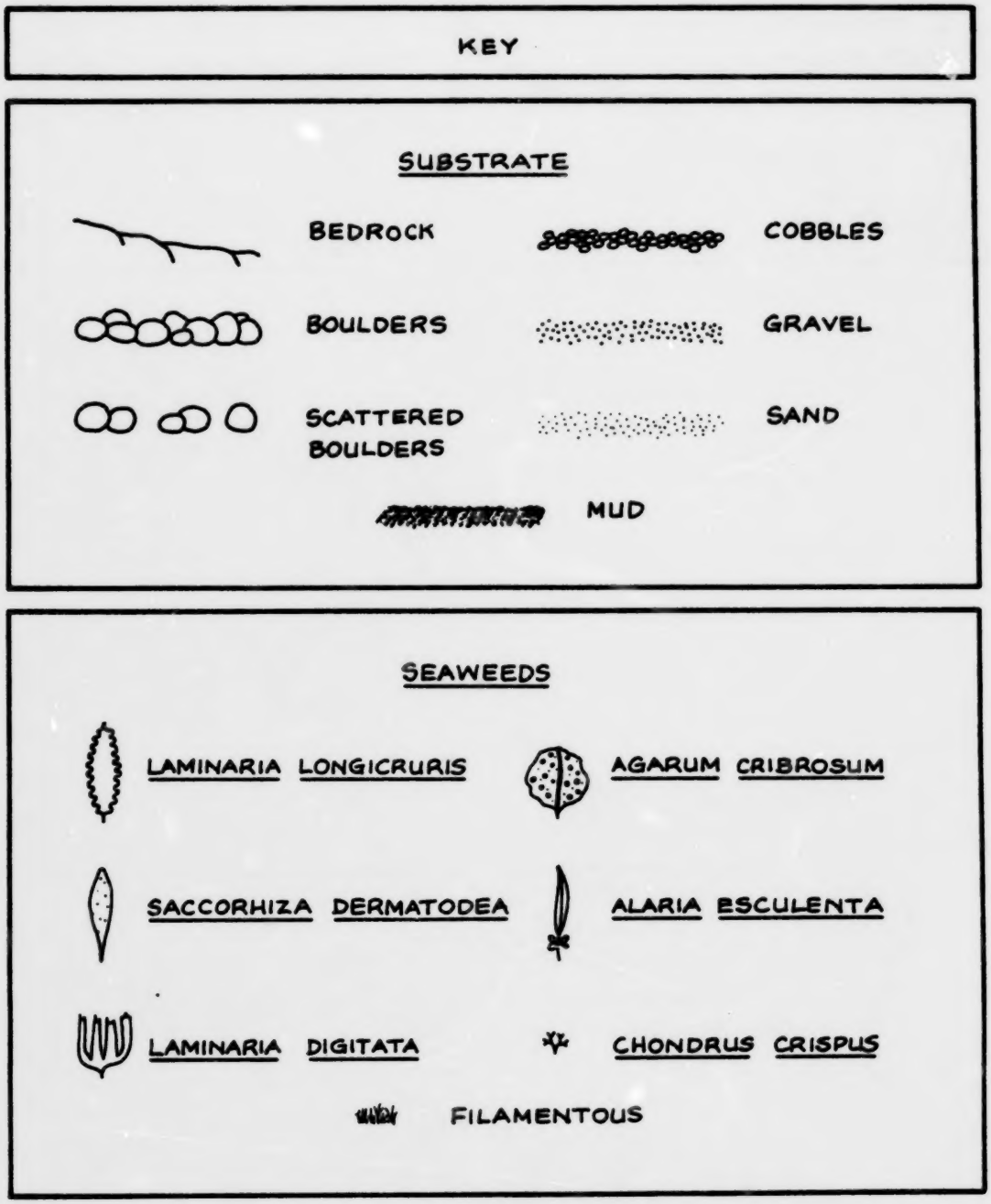
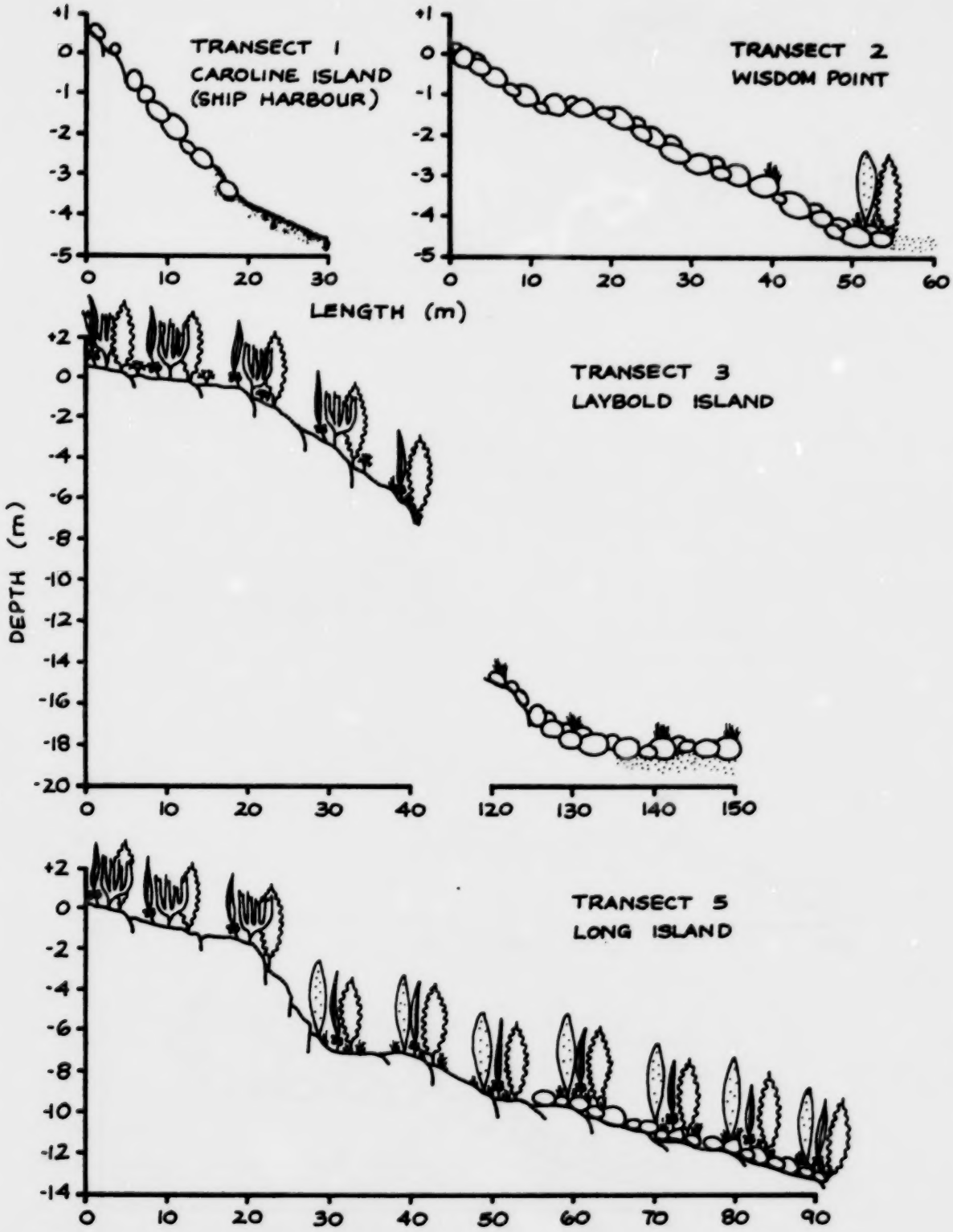


Figure 2. Profiles of transects surveyed showing depth, substrate type, and seaweed types.



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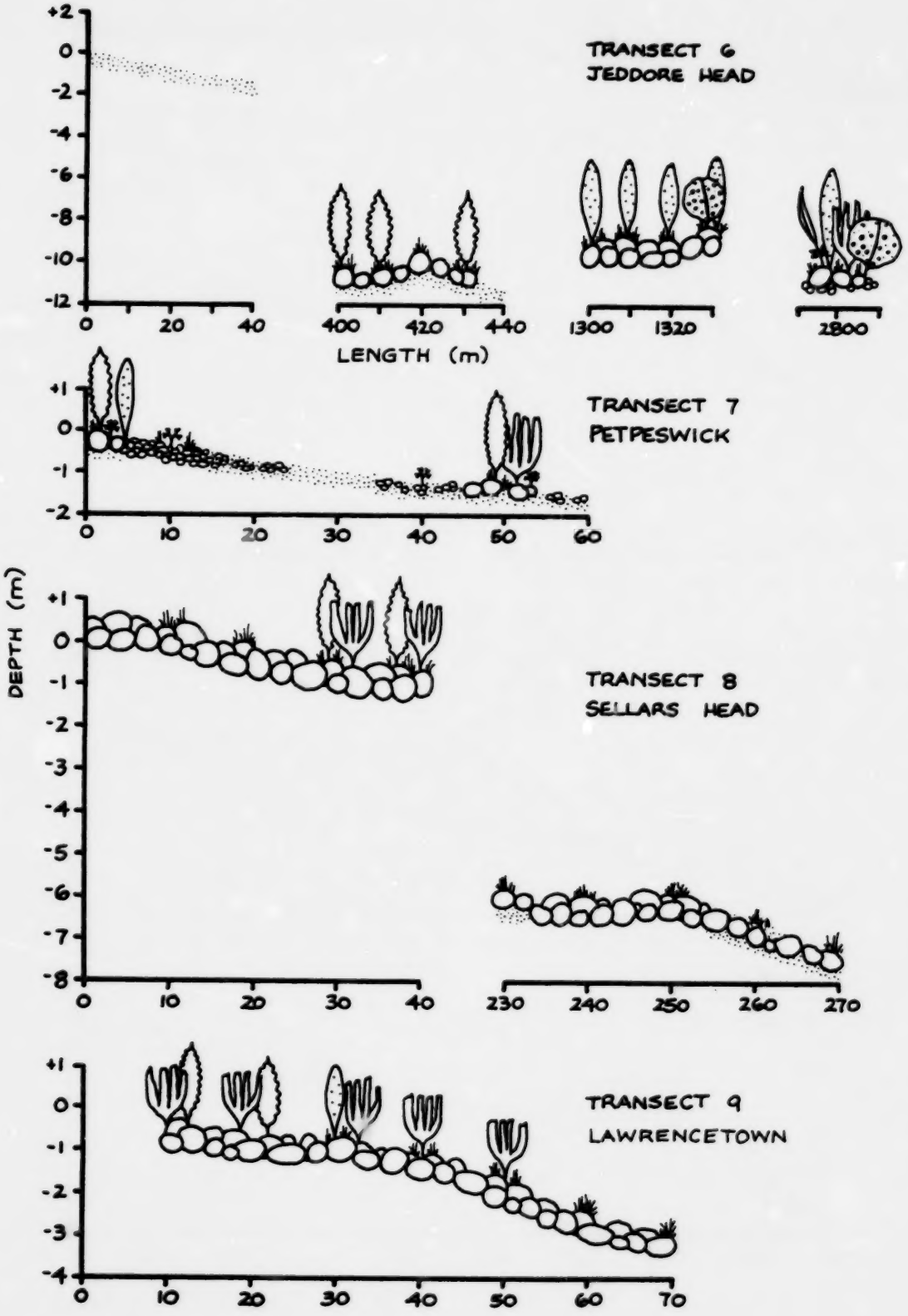

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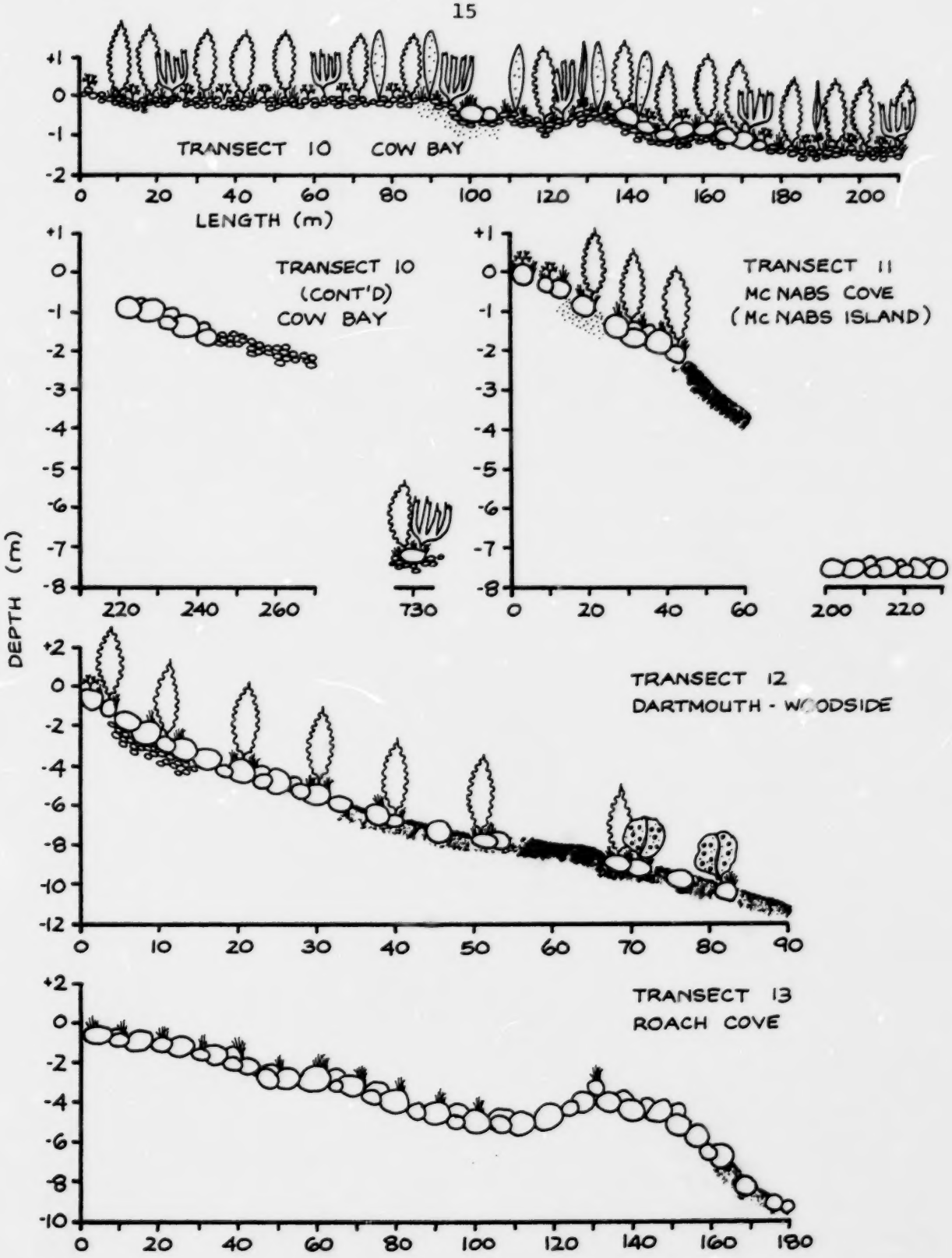

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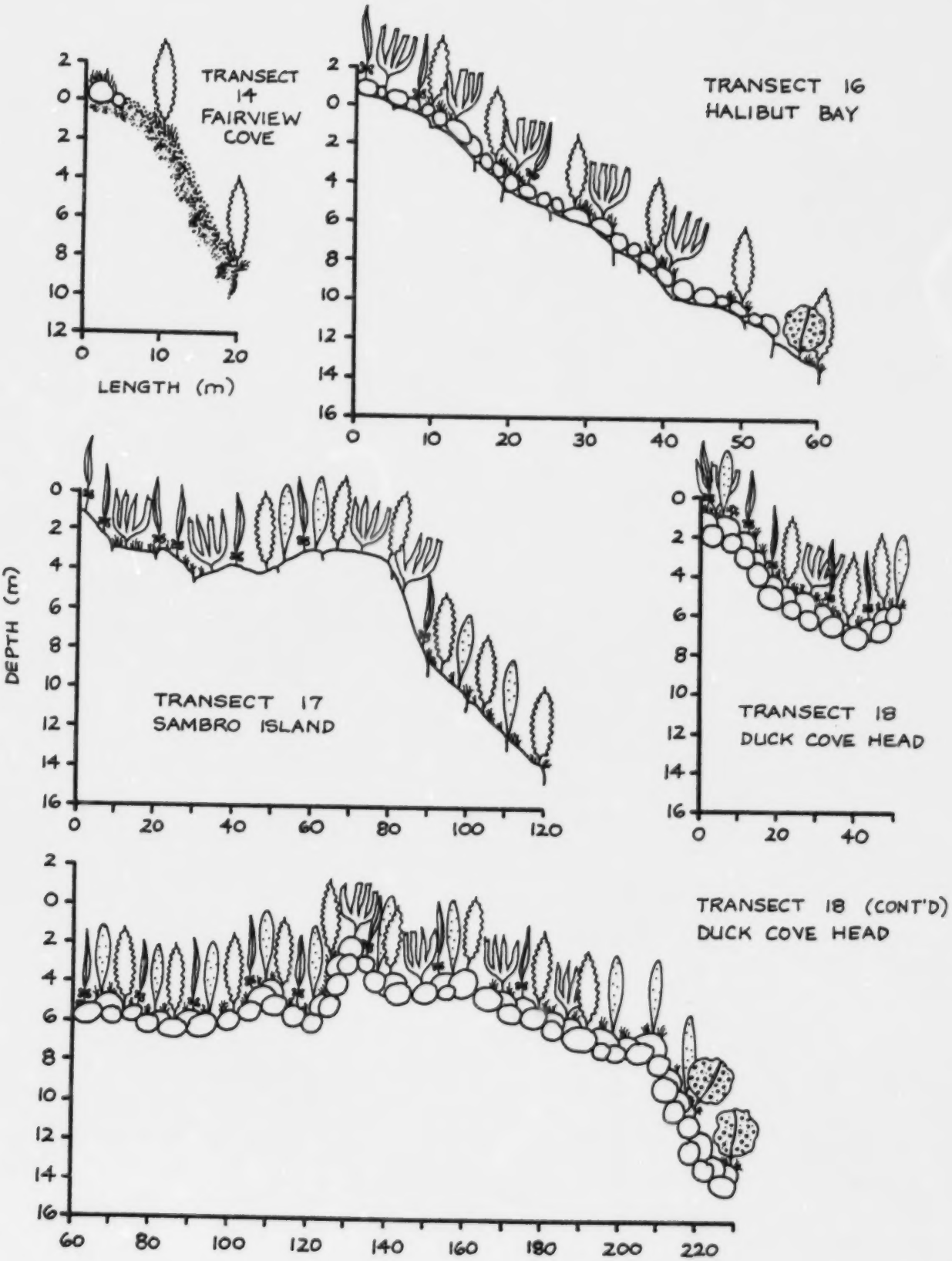

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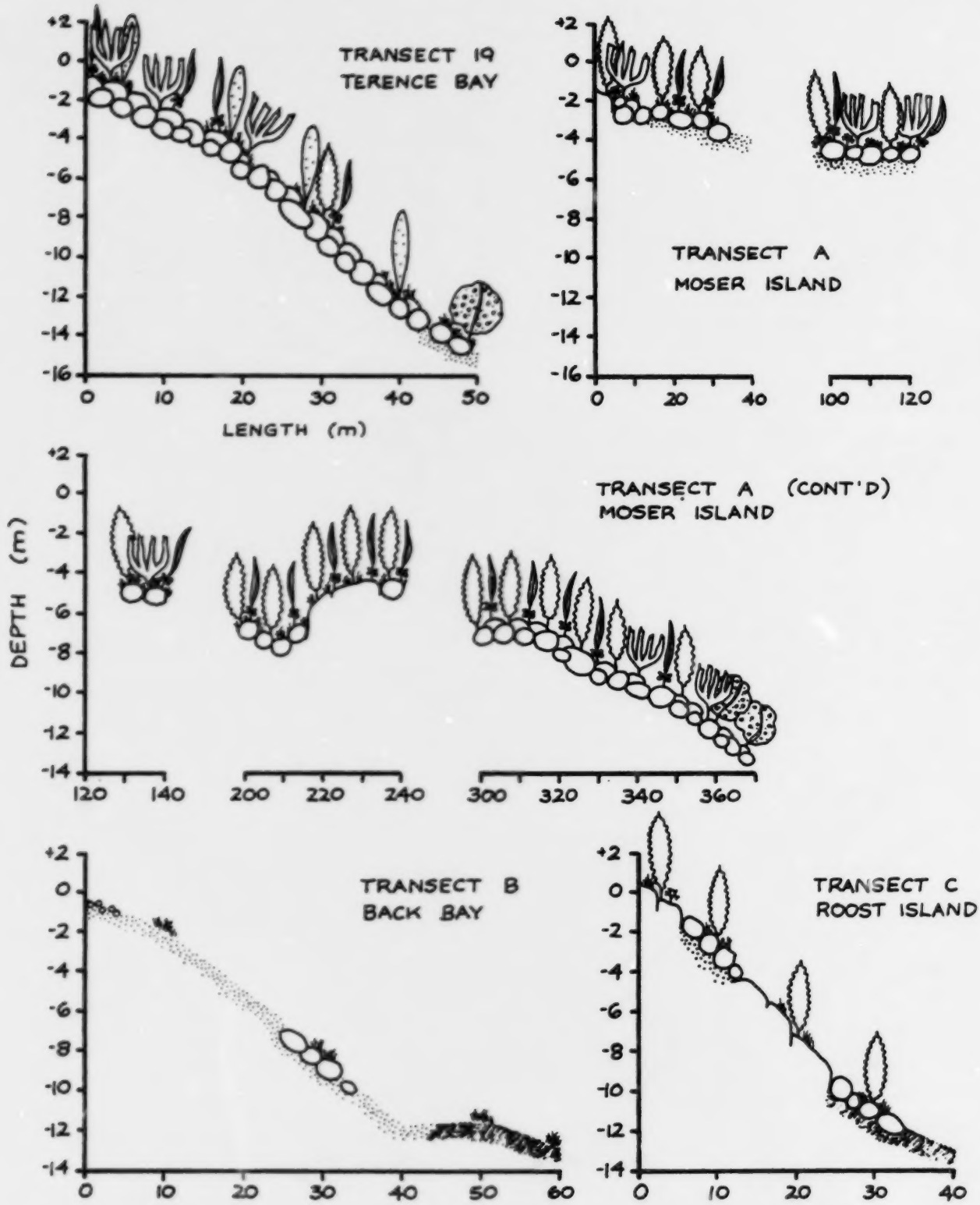

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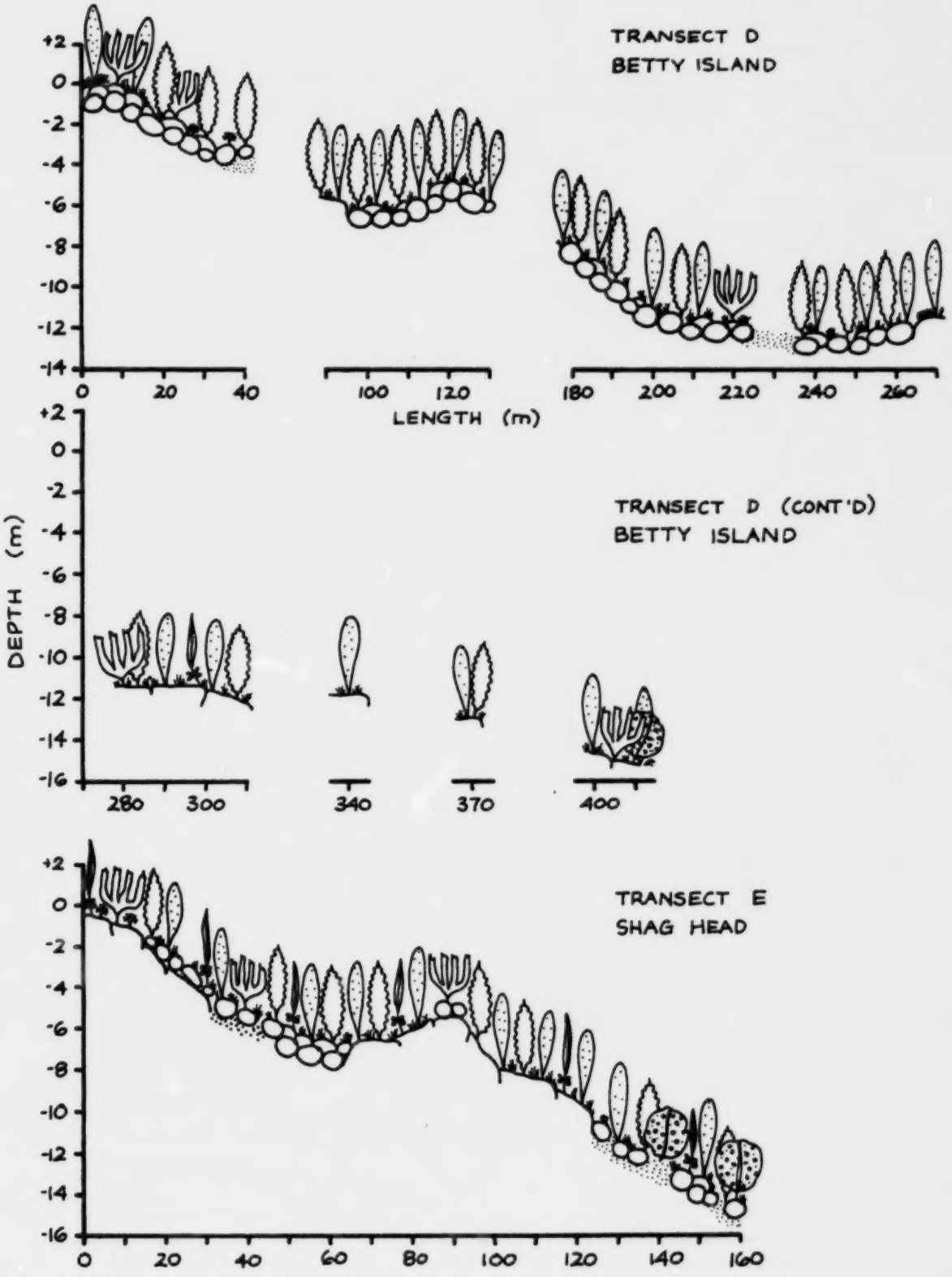

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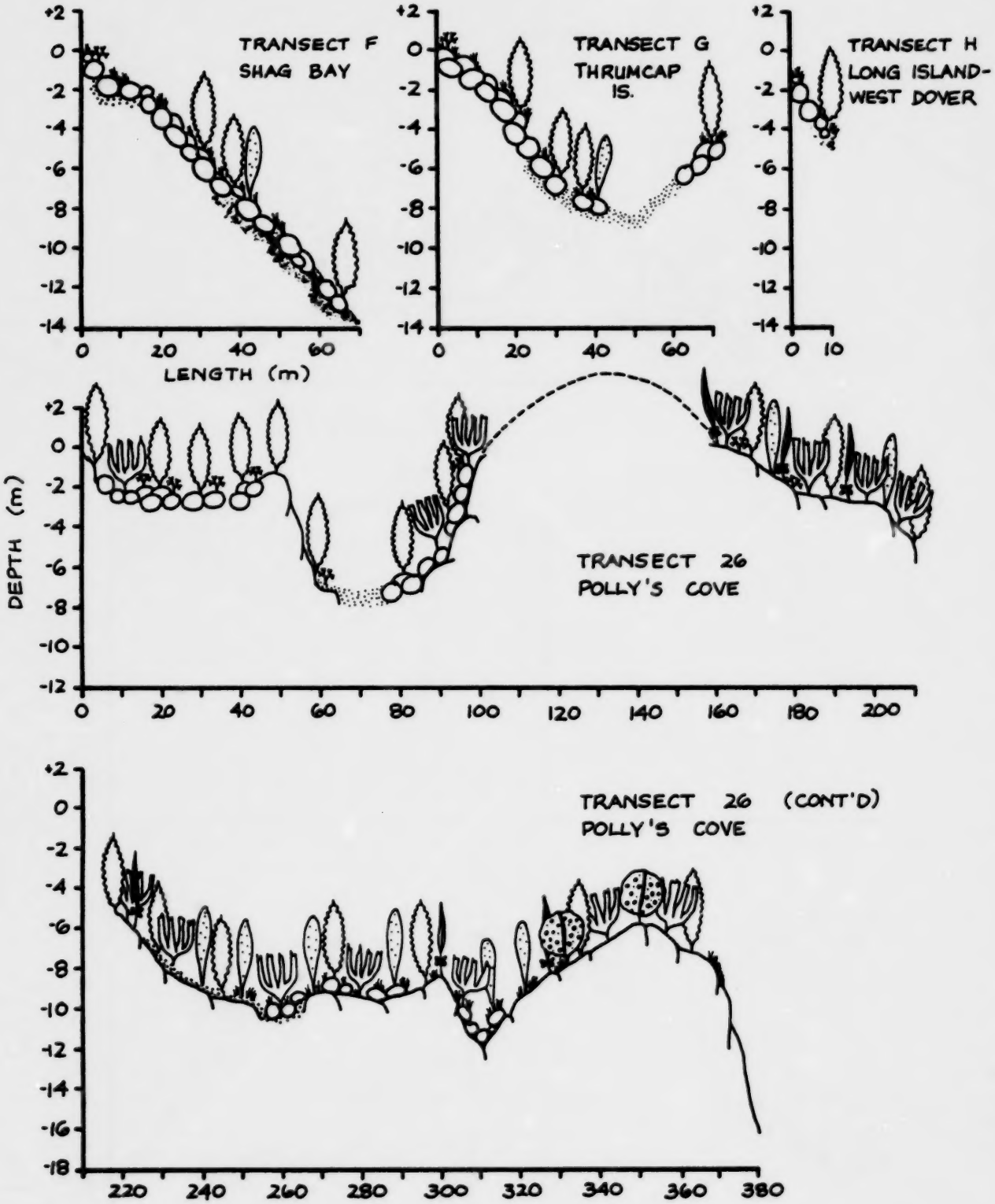

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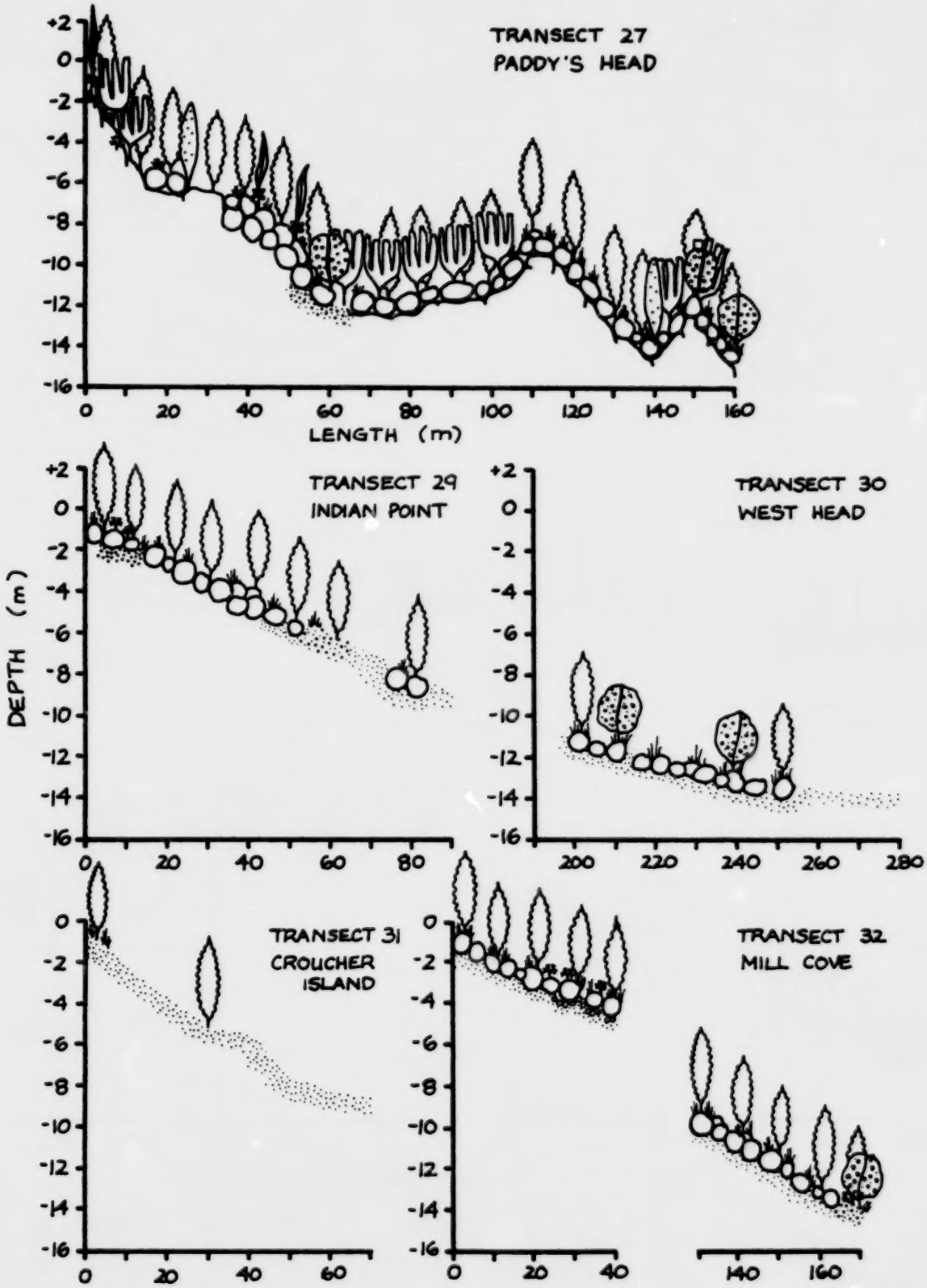

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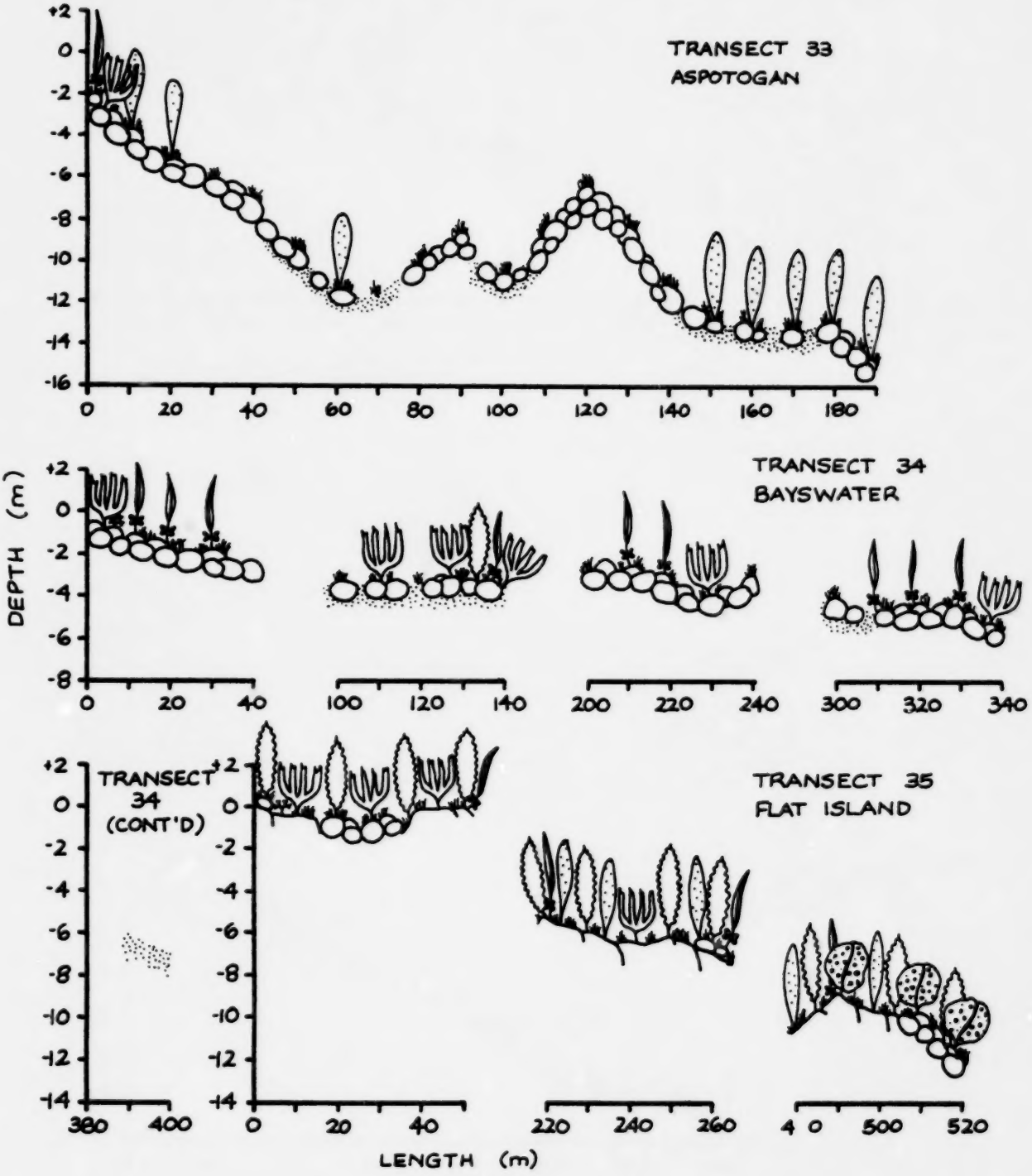

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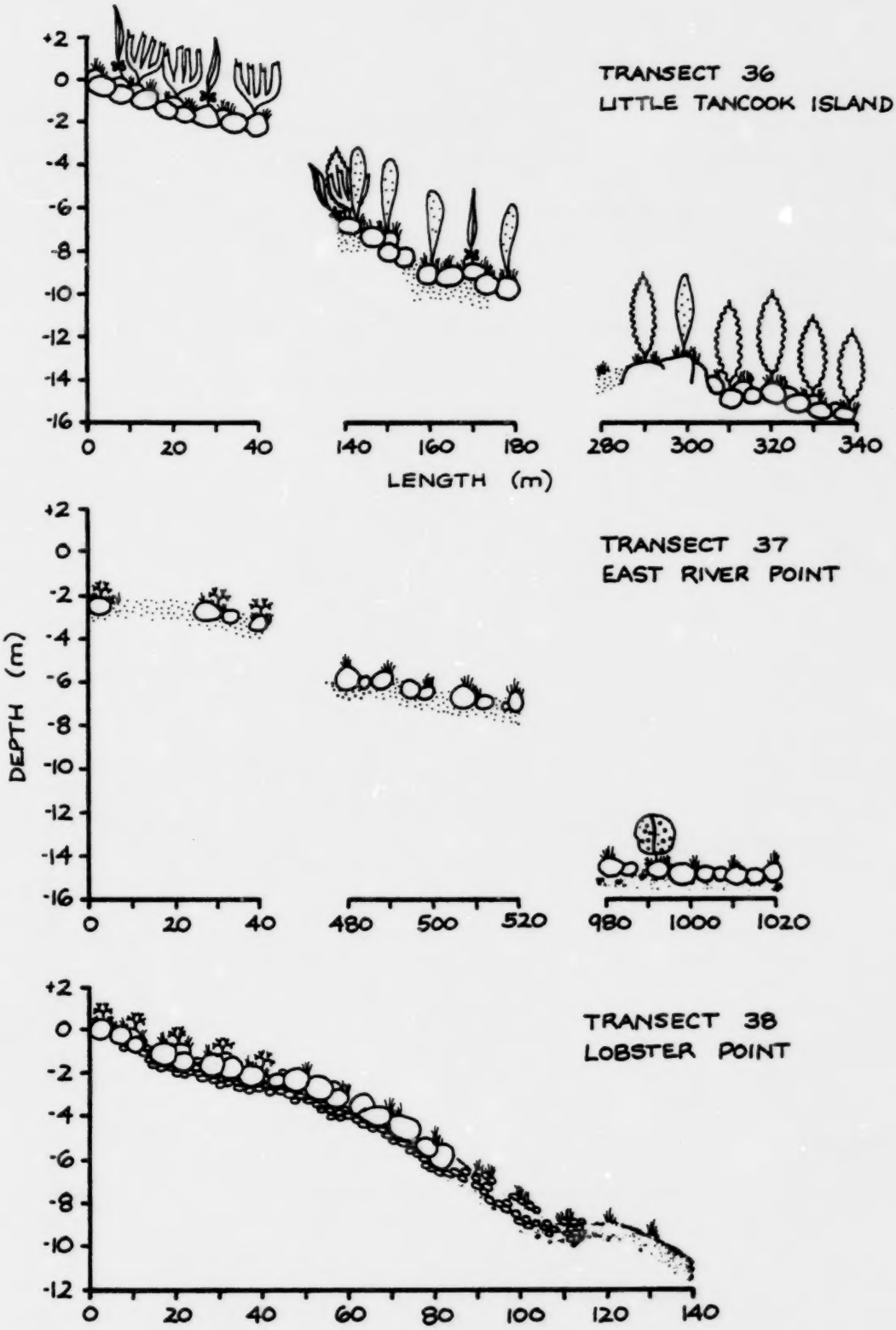

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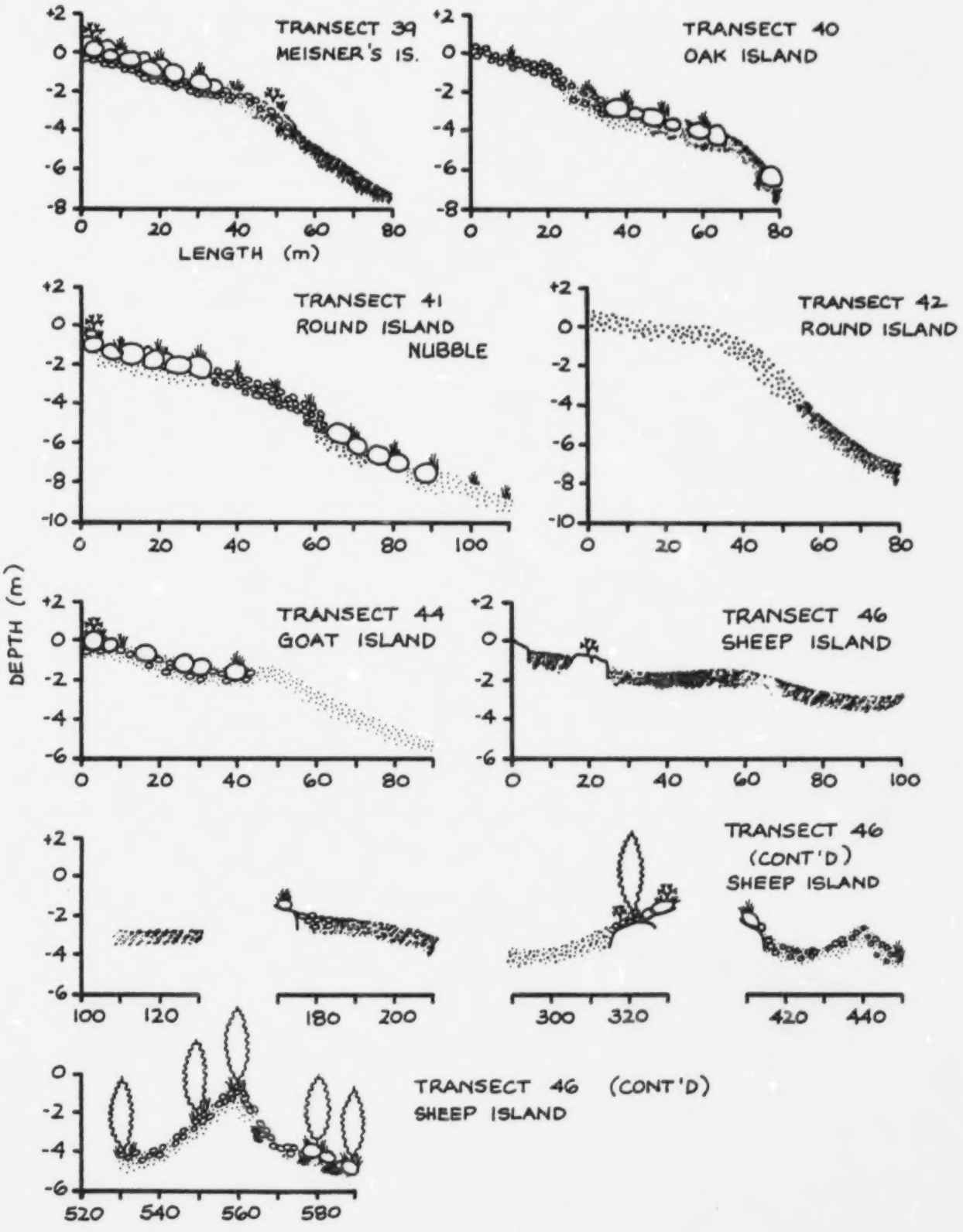
TRANSECT 39
MEISNER'S IS.
TRANSECT 40
OAK ISLAND
LENGTH (m)
TRANSECT 41
ROUND ISLAND
NUBBLE
TRANSECT 42
ROUND ISLAND
DEPTH (m)
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TRANSECT 46
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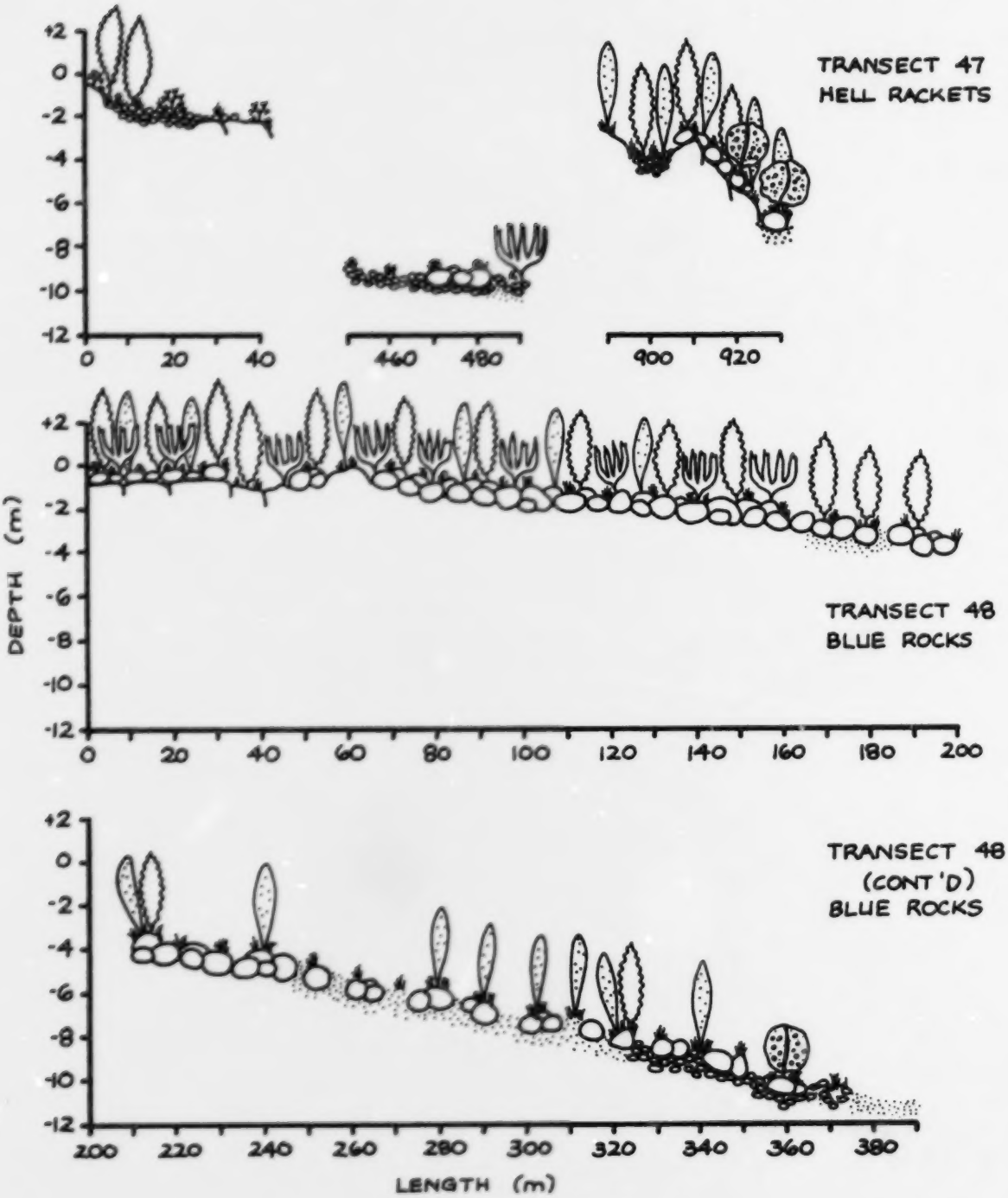

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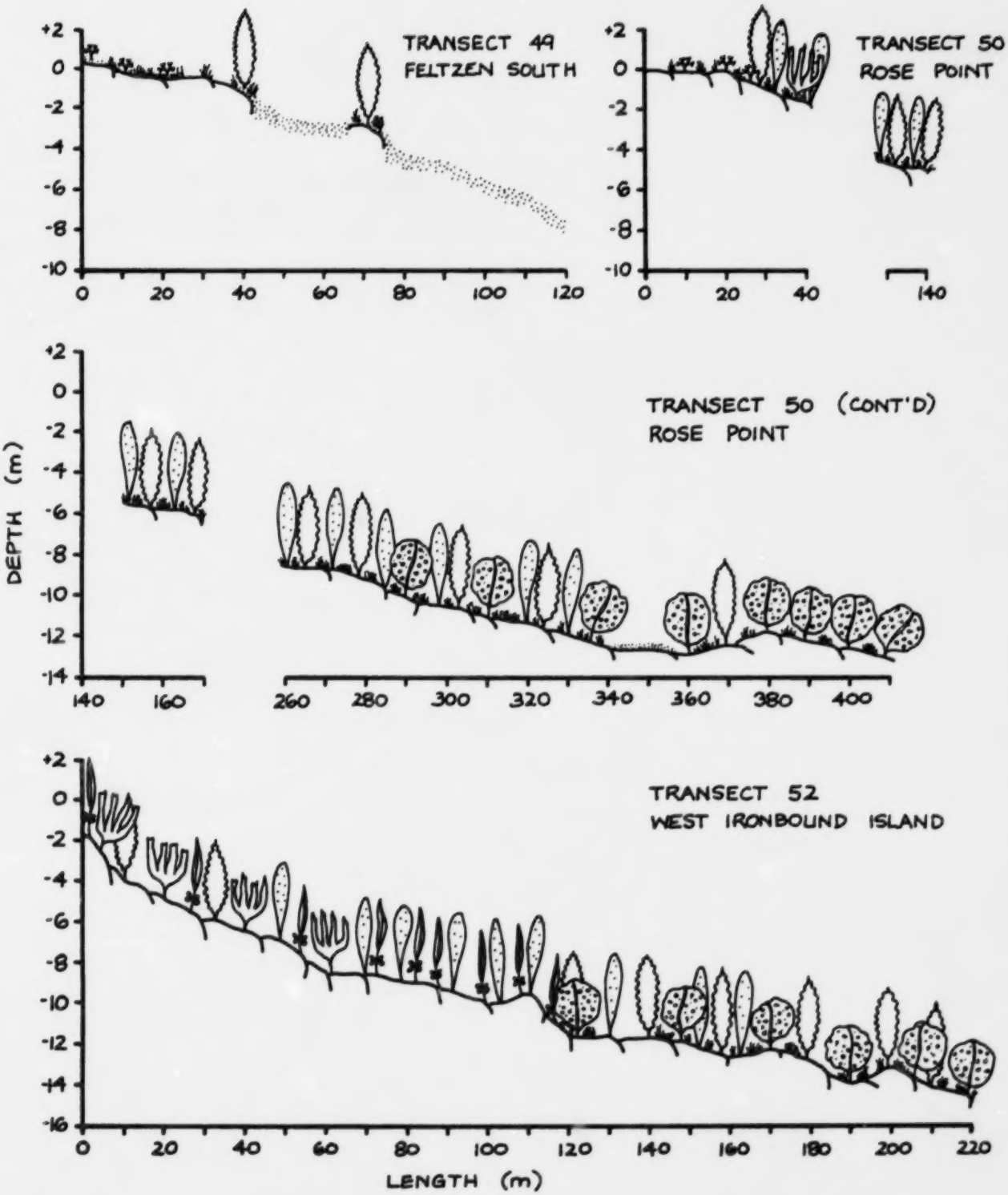

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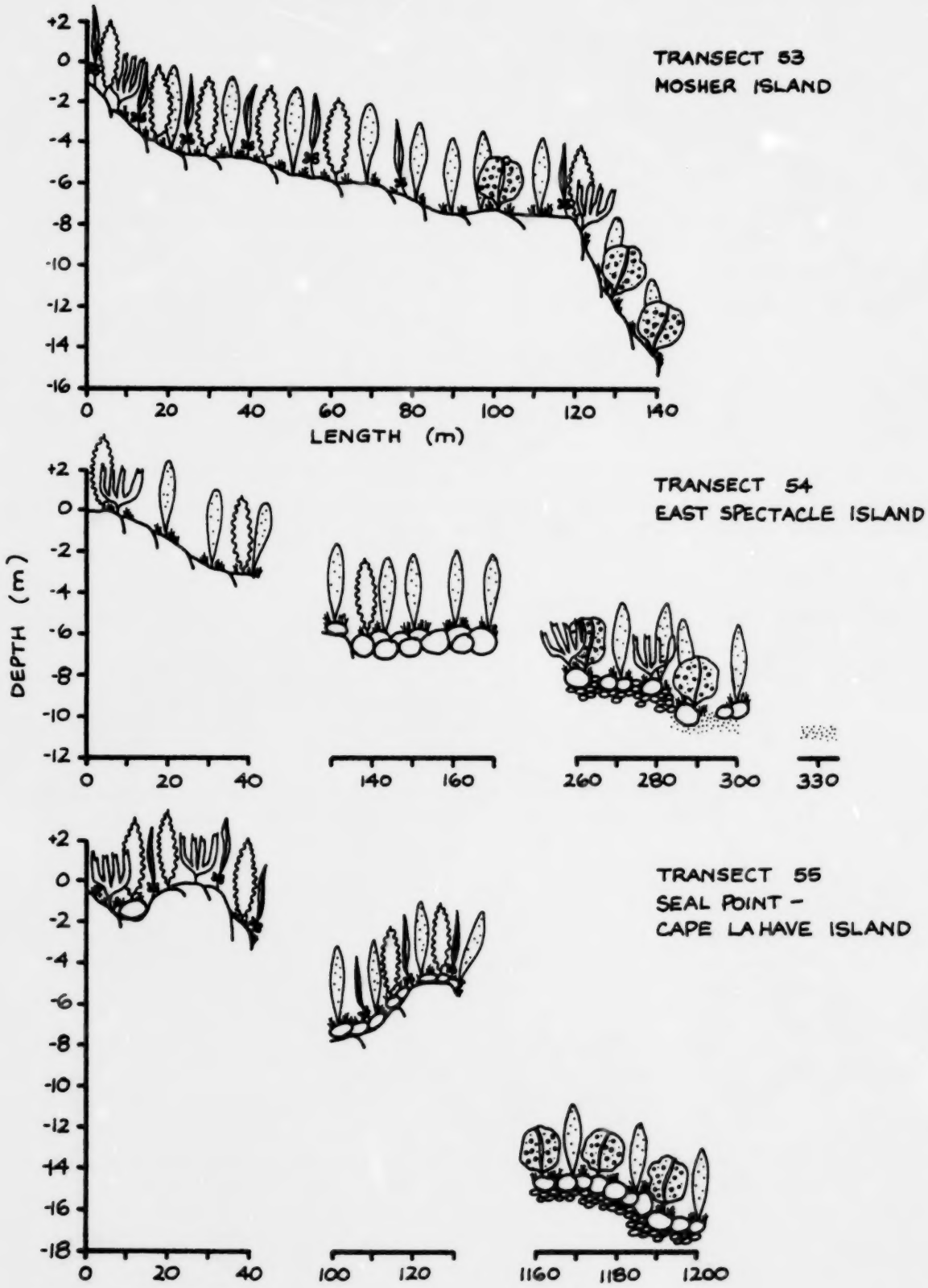

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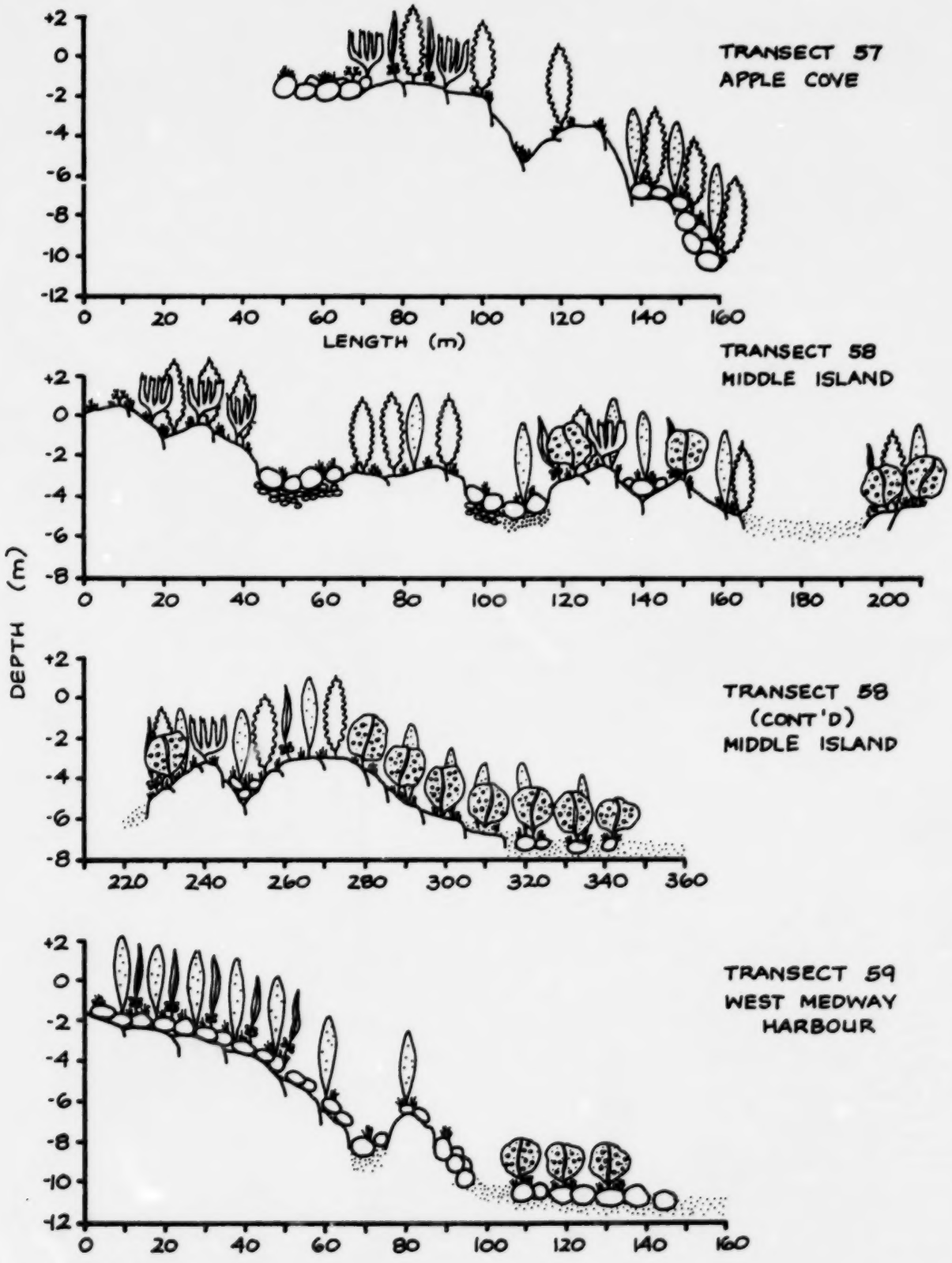

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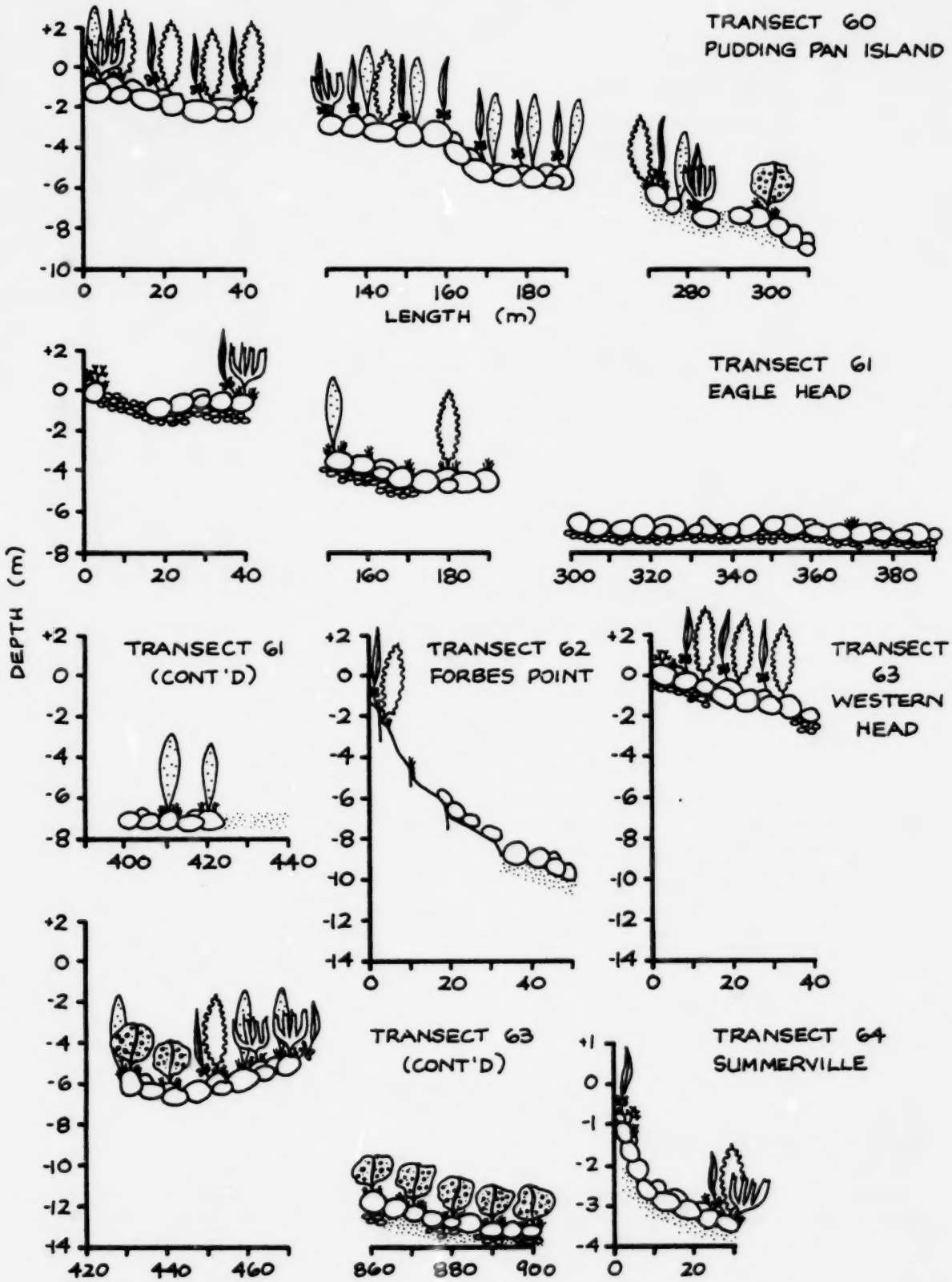

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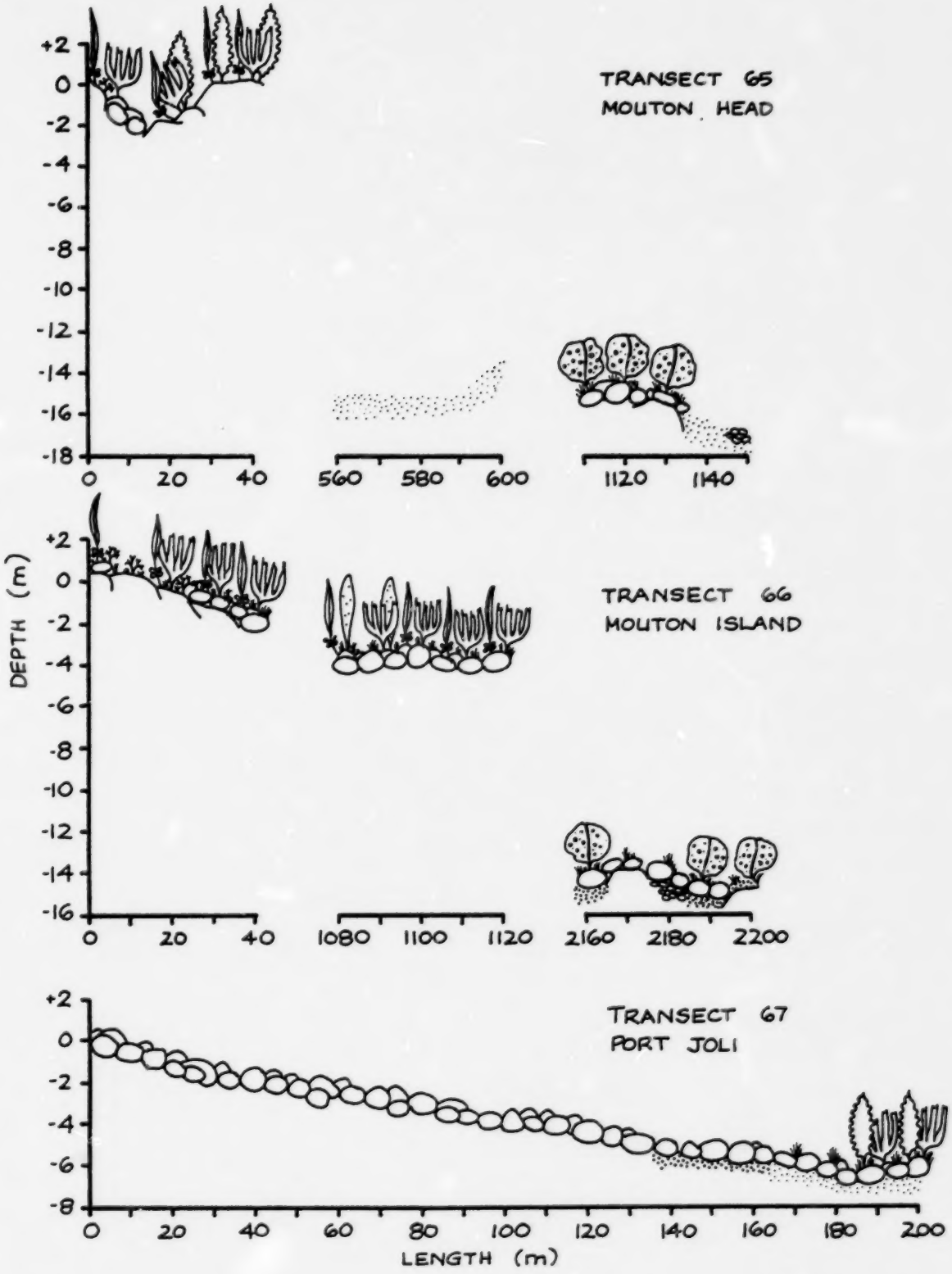

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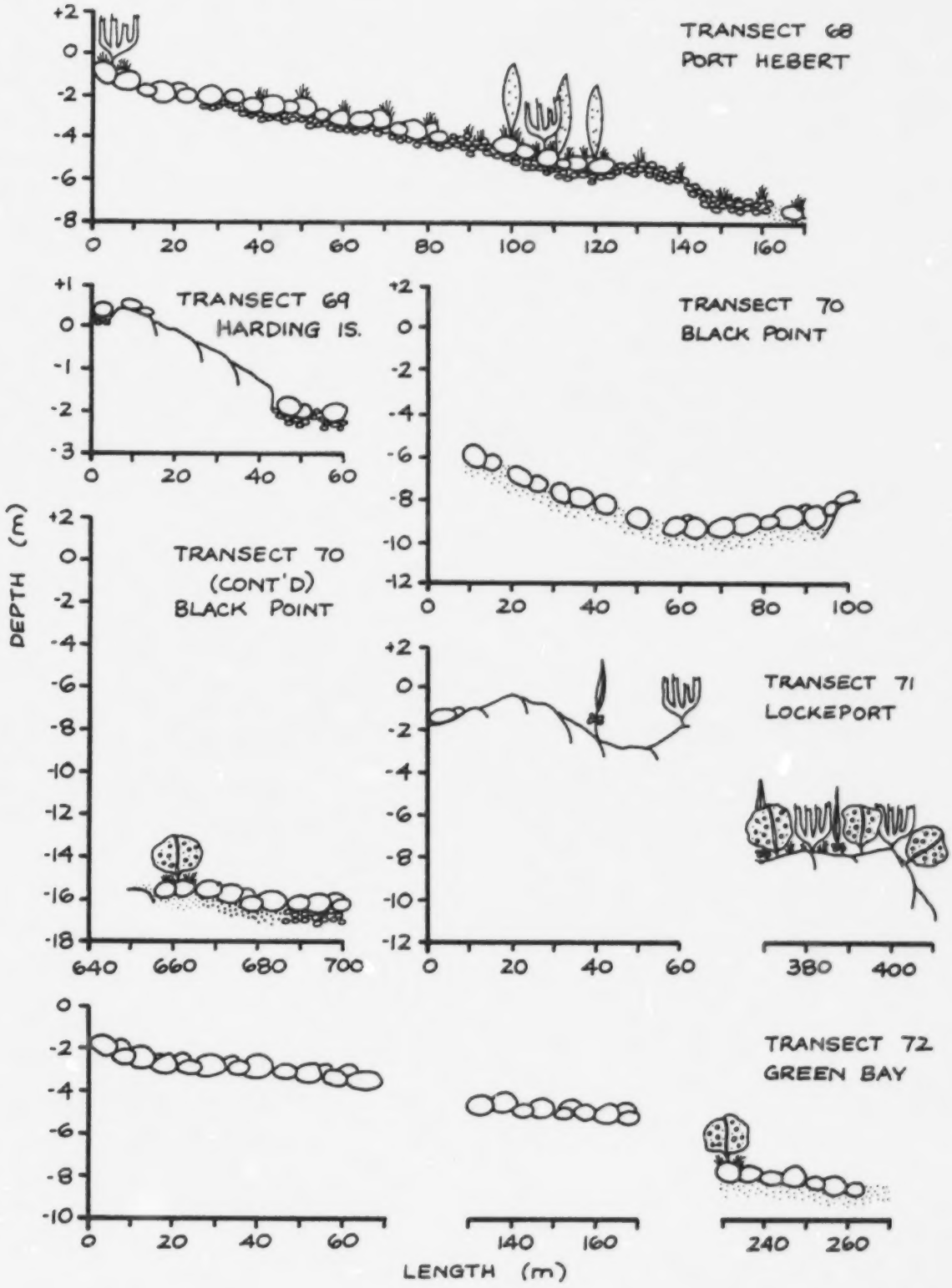

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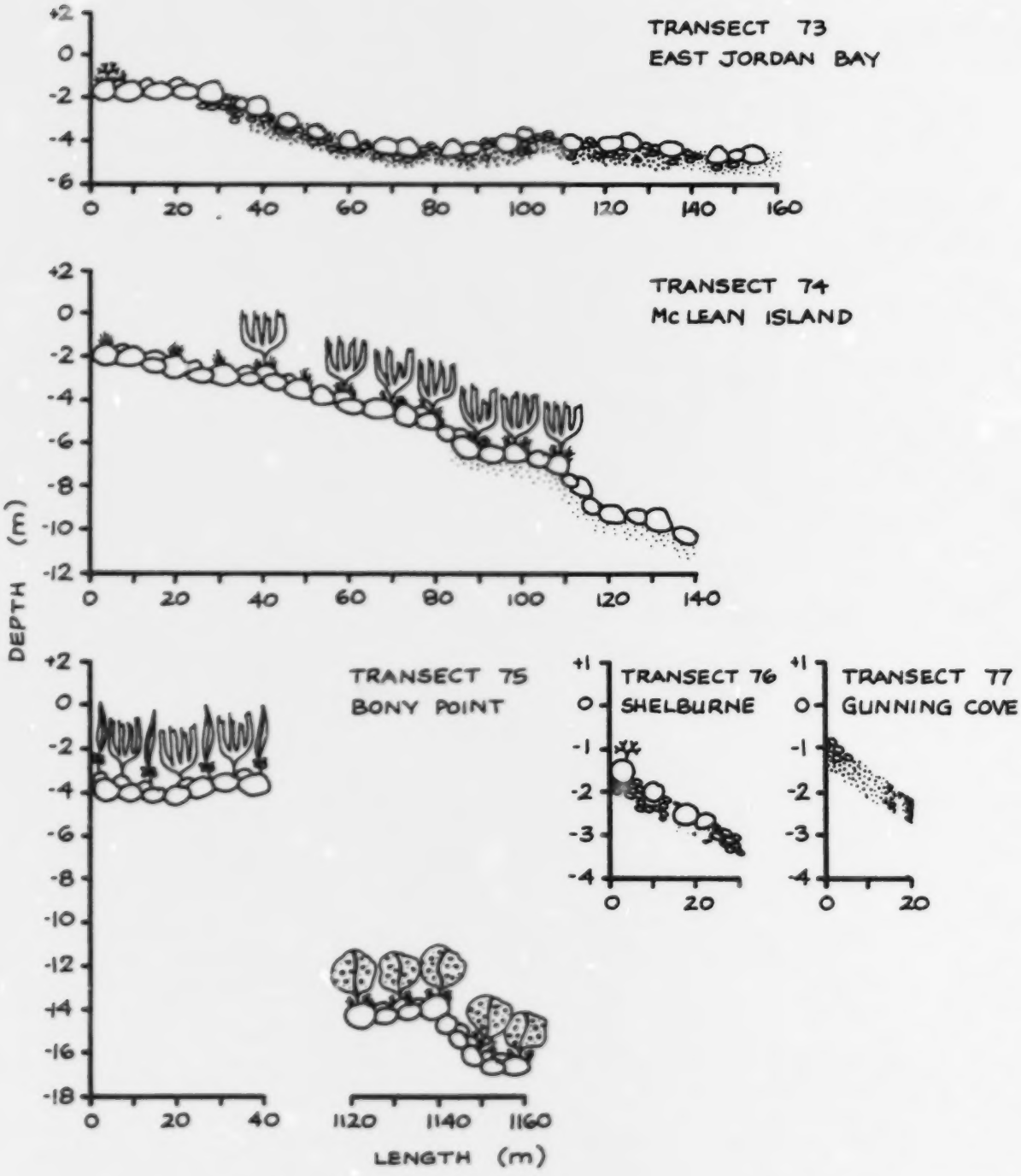

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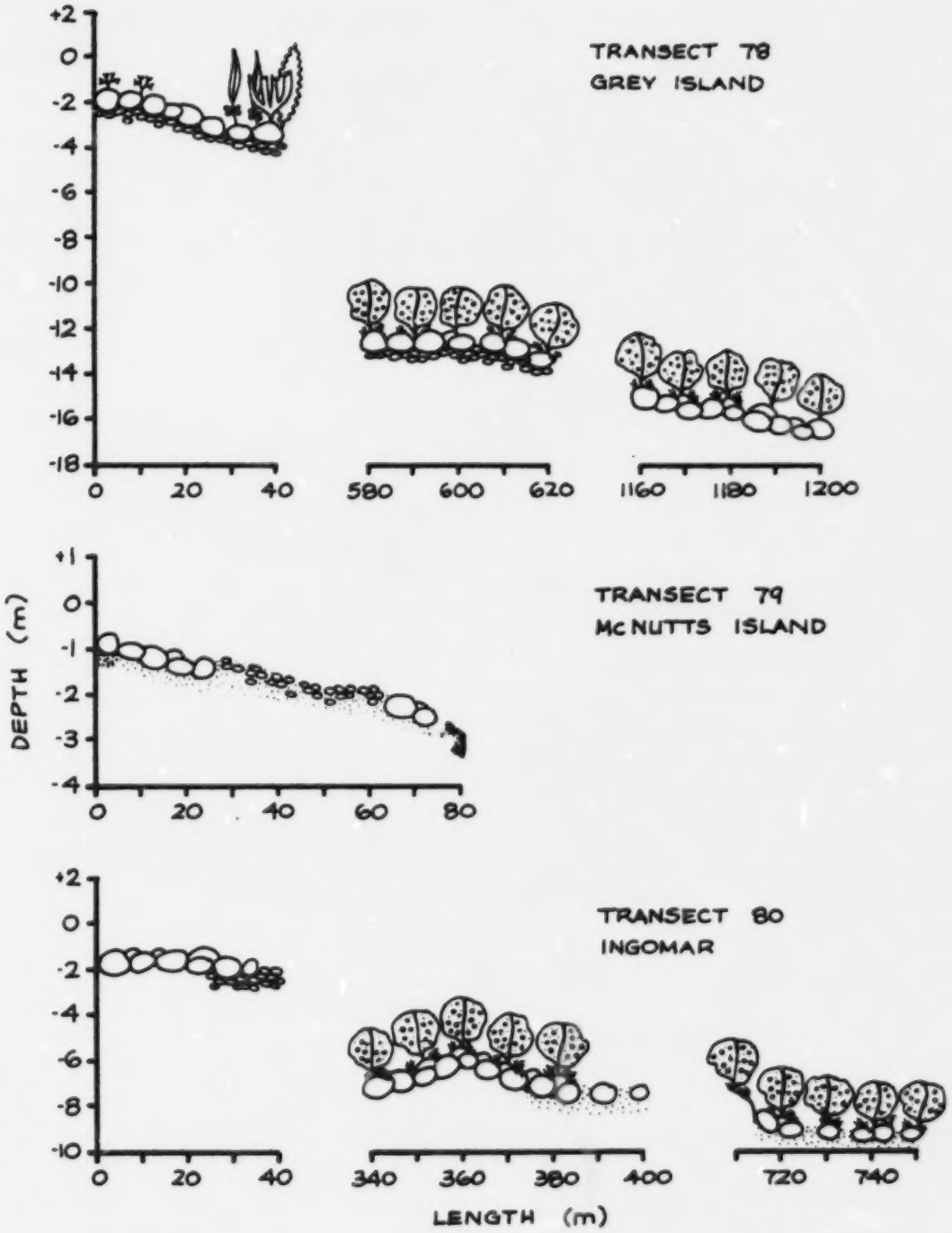

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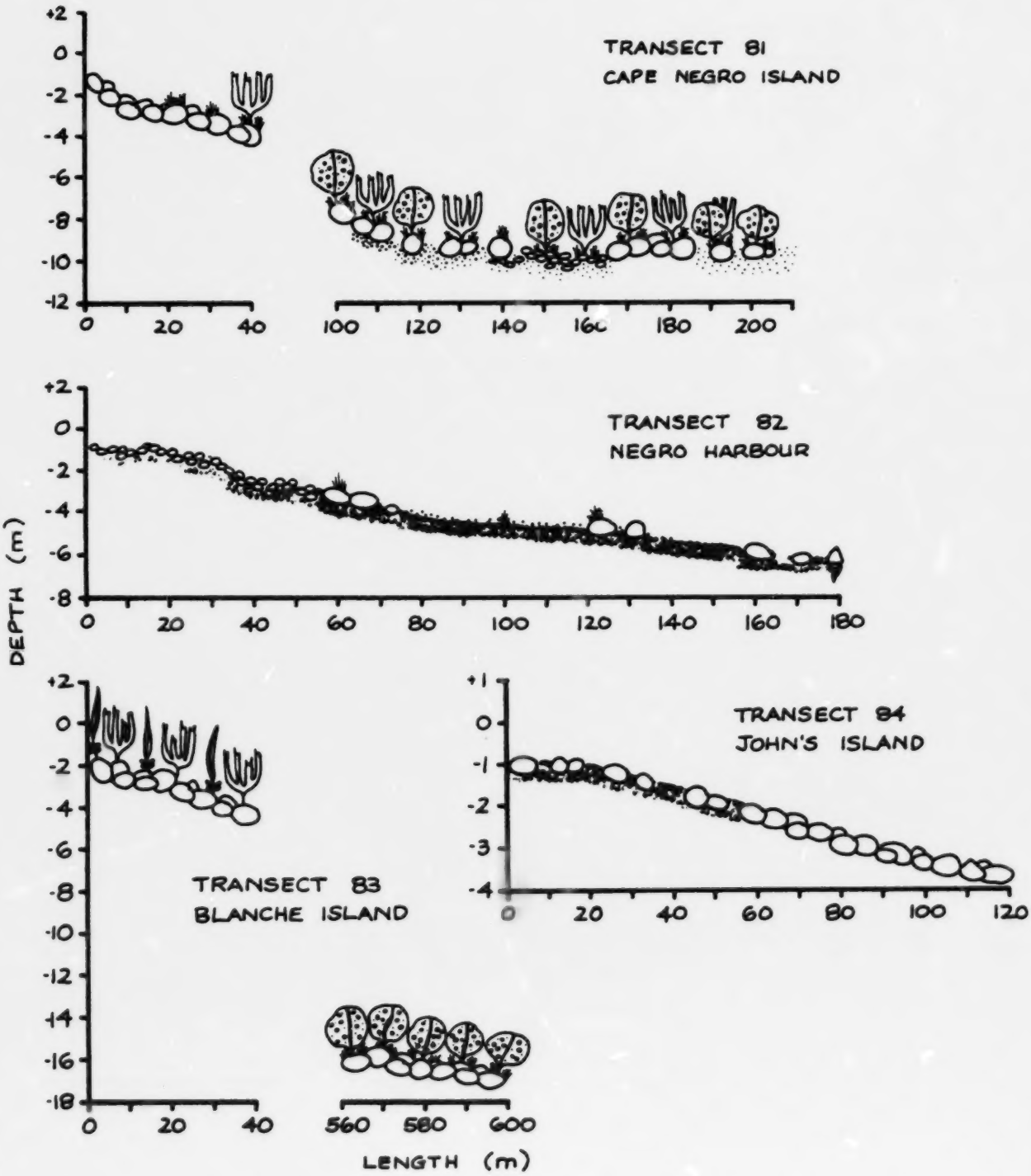

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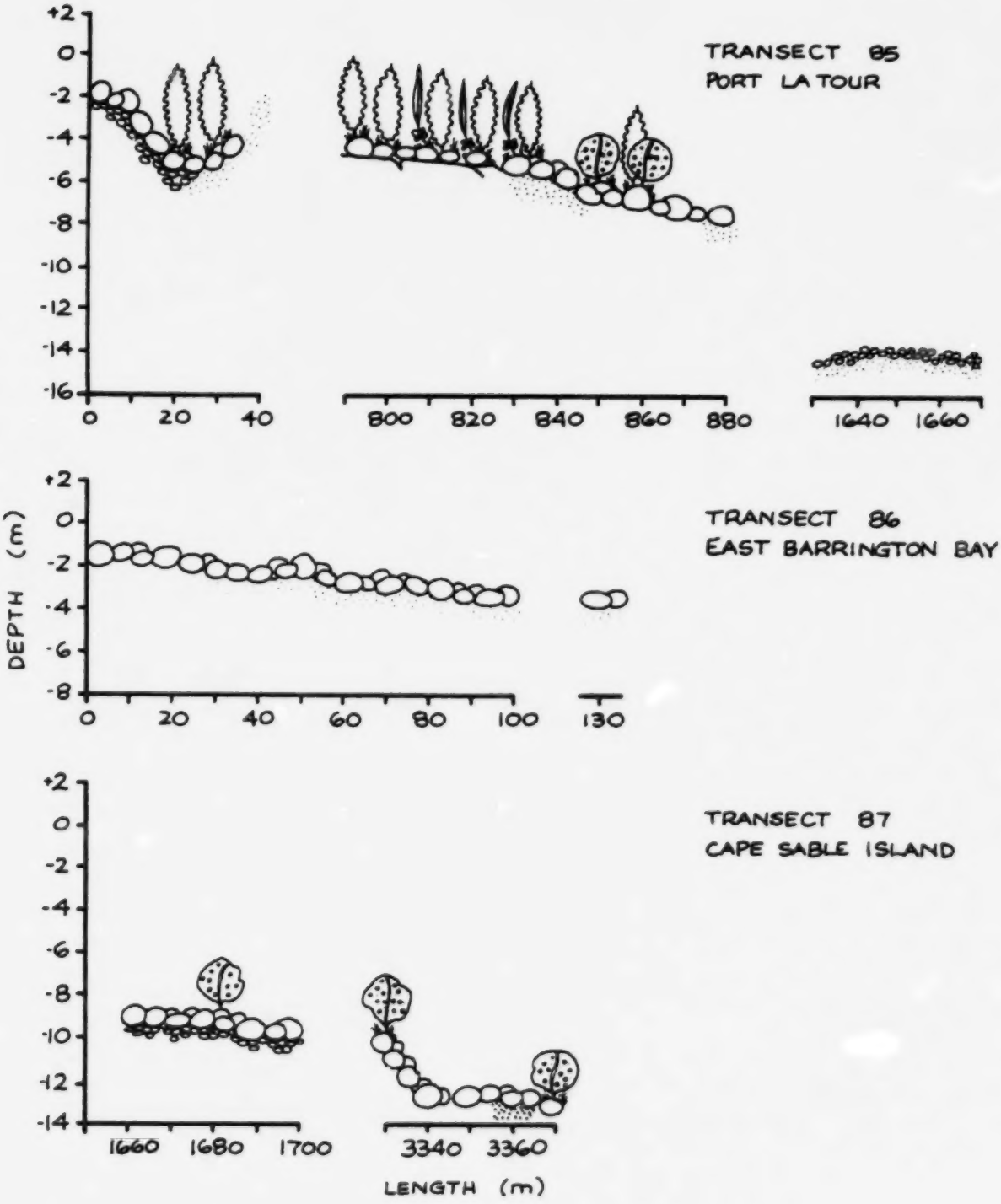

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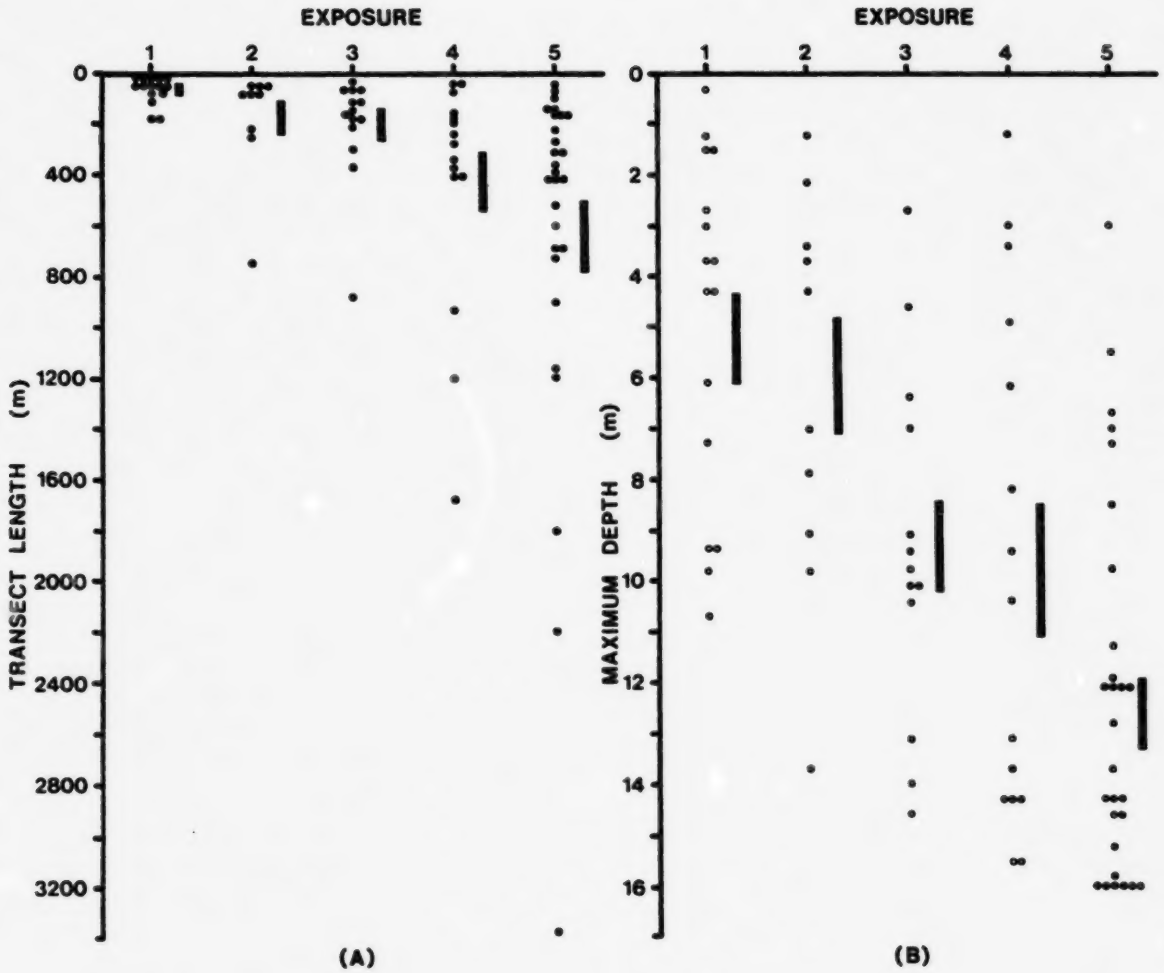
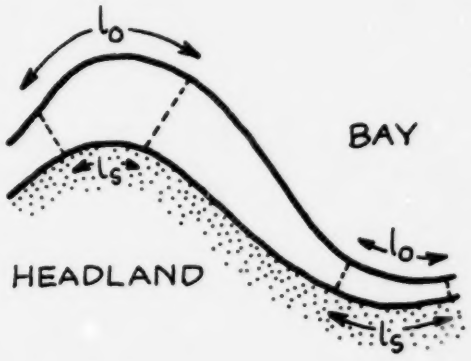


Figure 3. Transect length and depth by exposure. Bars represent means $\pm$ 1 sd.

$$l_e = \frac{t_e}{T} L$$

This calculation assumes that the transect locations were an unbiased sample of the true proportion of shoreline exposures. We have no reason to doubt this assumption.

The area of suitable habitat for each exposure class was the product of the length of shoreline (l_e) and the average transect length for that exposure. Theoretically, this could produce a biased result since the calculated area would be less than the actual area of a polygon on a headland. This is because the shoreline length (l_s) is less than the length of the outside of the polygon (l_o), as shown below. The opposite would be true in bays.



This bias was checked using a planimeter to calculate the actual areas of habitat adjacent to 10% of the most exposed shoreline and 15% of the most sheltered shoreline. The actual areas were found to be within 5% of those estimated using the shoreline lengths and mean transect lengths.

Most of the suitable habitat was found in exposed locations, 82% in Exposures 4 and 5 combined, whereas the length of shoreline in these exposure classes is only 26% of the total 2,900 km of shoreline.

AREAS OF SEA URCHIN MASS MORTALITY

This more extensive survey (Fig. 1; Table 2) confirmed that the area of mass mortalities was similar to the Ship Harbour to Medway Harbour estimate given in Miller and Colodey (1983). Transects 1 and 2, within Ship Harbour and 5 km east of Ship Harbour, still contained abundant sea urchins. Transect 8 also had an abundance (10-100/m^2) of large sea urchins, although less than was present before the 1981 mass mortalities [$>100/m^2$ (Miller and Colodey, 1983)]. Transect 13 in the Bedford Basin was the only other transect where any significant number of sea urchin was noted, but these were mostly less than 5 mm and all less than 20 mm in diameter. Based on sea urchin growth rates in St. Margaret's Bay (Miller and Mann, 1973) Bedford Basin urchins were small enough to have been recruited

Table 2. A summary of transect data (length, maximum depth, abundance of urchins, exposure index, and mean percentage of algal cover).

Transect No.	Length of suitable habitat (m)	Max. depth (m)	Urchins per m^2	Exposure index	Mean % algal cover	Transect No.	Length of suitable habitat (m)	Max. depth (m)	Urchins per m^2	Exposure index	Mean % algal cover
1	20	3.7	10-100	1	0	26	310	16.5	<1	5	68
2	50	4.3	10-100	2	3	27	160	14.3	<1	4	87
3	150	17.7	<1	5	44	28[a]	-	-	-	-	-
4[a]	-	-	-	-	-	29	80	7.9	<1	2	61
5	90	13.1	<1	5	81	30	50	13.1	<1	3	88
6	1,800	11.3	<1	5	69	31	10	0.3	<1	1	10
7	50	1.2	<1	2	32	32	170	14.0	<1	3	60
8	270	7.3	10-100	5	30	33	180	13.1	<1	4	66
9	70	3.0	<1	5	37	34	390	5.5	<1	5	46
10	730	7.0	<1	5	14	35	520	11.9	<1	5	70
11	40	1.5	<1	1	74	36	340	15.5	<1	4	78
12	70	9.4	<1	1	93	37	880	14.6	<1	3	55
13	180	9.4	10-100	1	34	38	110	9.1	<1	3	38
14	20	.8	<1	1	50	39	50	2.7	<1	1	30
15[a]	-	-	-	-	-	40	60	3.4	<1	2	34
16	60	14.3	<1	5	84	41	90	7.0	<1	1	40
17	120	13.7	<1	5	91	42[a]	-	-	-	-	-
18	230	13.7	<1	4	93	43[a]	-	-	-	-	-
19	50	14.3	<1	4	87	44	40	1.2	<1	1	44
A	360	13.1	<1	5	55	45[a]	-	-	-	-	-
B[a]	-	-	-	-	-	46	400	4.9	<1	4	20
C	30	10.7	<1	1	48	47	930	9.4	<1	4	34
D	410	15.2	<1	5	89	48	370	10.1	<1	3	33
E	160	14.3	<1	5	62	49	50	2.7	<1	3	18
F	70	13.7	<1	2	24	50	410	13.1	<1	5	54
G	60	7.3	<1	1	61	51[a]	-	-	-	-	-
H	10	4.3	<1	1	50	52	220	14.6	<1	5	76

...Contd.

Table 2. Contd...

Transect No.	Length of suitable habitat (m)	Max. depth (m)	Urchins per m^2	Exposure index	Mean % algal cover	Transect No.	Length of suitable habitat (m)	Max. depth (m)	Urchins per m^2	Exposure index	Mean % algal cover
53	140	14.3	< 1	5	77	81	200	9.8	1-10	3	20
54	320	9.8	< 1	2	70	82	180	6.1	< 1	1	1
55	1,200	15.5	< 1	4	42	83	600	16.7	10-100	5	28
56	30	4.6	< 1	3	60	84	120	3.7	< 1	2	0
57	160	9.8	< 1	5	36	85	1,680	14.3	10-100	4	7
58	300	7.0	< 1	3	63	86	380	3.0	1-10	4	10
59	120	10.4	10-100	3	28	87	3,380	12.8	100+	5	3
60	310	8.5	100+	5	66						
61	420	6.7	10-100	5	8						
62	50	9.4	100+	3	5						
63	900	13.1	10-100	5	16						
64	30	3.4	10-100	4	33						
65	690	17.1	10-100	5	37						
66	2,200	14.6	10-100	5	31						
67	200	6.1	100+	4	7						
68	170	6.4	10-100	3	13						
69	60	1.2	100+	4	0						
70	700	15.8	100+	5	0						
71	410[b]	10.4	10-100	4	5						
72	260	8.2	10-100	4	0						
73	150	4.3	1-10	2	0						
74	140	10.1	1-10	3	11						
75	1,160	16.2	10-100	5	27						
76	30	3.0	1-10	1	20						
77	10	1.5	1-10	1	0						
78	1,200	16.2	10-100	5	14						
79	70	2.1	1-10	2	0						
80	750	9.1	10-100	2	11						

[a]These transects were on unsuitable habitat.
[b]Only 310 m used for average length for Exposure 4.

from the plankton since mass mortalities in 1980. The western boundary of mass mortalities was sharp, with sea urchins absent on the east side of Medway Harbour (Transect 58) but abundant on the west side.

West of Medway Harbour moribund or dead sea urchins were seen on 11 of 17 transects completed on or after October 14 (Table 3). On most of the transects mortalities were restricted to the shallow ends. The western extent of the mortalities observed was the eastern side of Barrington Bay (Transect 86).

Results of the helicopter survey for Medway Harbour and west (Table 4) support the findings from the diving survey. No accumulations were seen on the east side of Medway Harbour (Location 0) where mortality was near complete in 1981. Neither were accumulations seen on the west side of Barrington Bay (Locations 210 and 217) where only healthy sea urchins were seen by divers, nor west of Cape Sable Island (Location 220). Of the 29 locations visited in between, accumulations were seen at 23.

The same data treatment is provided in Table 5 for helicopter survey results east of Ship Harbour. Again, most areas showed evidence of recent sea urchin mortalities. No underwater surveys were conducted in this area in 1982.

PERCENTAGE COVER BY MACROPHYTES

A single value of percentage cover was determined for each transect and means calculated among the transects for each exposure with and without sea urchins (Table 6). For most transects without sea urchins the sea urchins are known to have died in the autumn of 1981; but, for two transects near the mouth of Halifax Harbour, mass mortalities occurred in 1980. Percentage cover for these two transects is also presented.

For every exposure there is an increase in percentage cover from transects with sea urchins to transects without sea urchins to transects known to be without sea urchins for two years. Thus, algal recovery following sea urchin mass mortalities is clearly indicated.

OCCURRENCE OF ALGAL TAXA

Figure 4 and Table 7 illustrate recovery of principle plant taxa by depth and exposure. These data are based on presence or absence at each of the 1,044 stations occupied. The number of stations at each exposure is shown in Table 8.

Differences between algal occurrence, by exposure, in areas with urchins and areas without urchins for one year were tested with a 2 x 2 chi-square contingency table; and the results are given in Table 9.

Table 3. Locations and dates where sea urchin mortalities were observed in the 1982 transect survey.

Transect No.	Date	Mean no. urchins/m^2	Maximum depth of sick urchins (m)
71	Nov. 18	10-100	3.0
72	Oct. 19	10-100	8.2
73	Oct. 14	1-10	4.3
75	Oct. 19	1-10	3.4
78	Oct. 19	10-100	3.0
80	Oct. 20	10-100	9.1
81	Oct. 20	1-10	7.0
82	Oct. 20	<1	3.4
83	Oct. 20	10-100	4.0
84	Oct. 20	<1	3.4
86	Oct. 27	1-10	3.0

Table 4. Density of dead sea urchins on exposed beaches (number/m of beach) from Medway Harbour to Cape Sable Island. Locations are straight-line distances (km) west of the east side of Medway Harbour

Location	Density	Location	Density
0	<1	65	10-100
2	10-100	67	1-10
7	10-100	72	100-1,000
10	<1	75	1-10
12	<1	77	<1
15	<1	82	10-100
17	1-10	83	1-10
27	1-10	90	10-100
30	<1	92	10-100
32	1-10	97	10-100
35	1-10	100	10-100
37	<1	100	100-1,000
42	1-10	205	100-1,000
50	1-10	210	<1
55	10-100	217	<1
60	10-100	220	<1
62	10-100		

Table 5. Density of dead sea urchins on exposed beaches (number/m of beach) from near Ship Harbour to western Cape Breton. Locations are straight-line distances (km) east of Ship Harbour.

Location	Density	Location	Density
-5	<1	90	10-100
2	10-100	108	<1
12	1-10	115	10-100
20	10-100	128	1-10
30	100-1,000	138	10-100
40	10-100	158	10-100
55	1-10	170	<1
63	1-10	173	1-10
73	10-100	178	1-10
83	10-100	195	1-10

Table 6. Percentage cover of seaweed by exposure on transects with sea urchins, without sea urchins, and without sea urchins since 1980.

	Exposure				
	1	2	3	4	5
With sea urchins	11	3	15	9	24
Without sea urchins	50	44	52	63	62
Without sea urchins since 1980	-	-	-	87	84

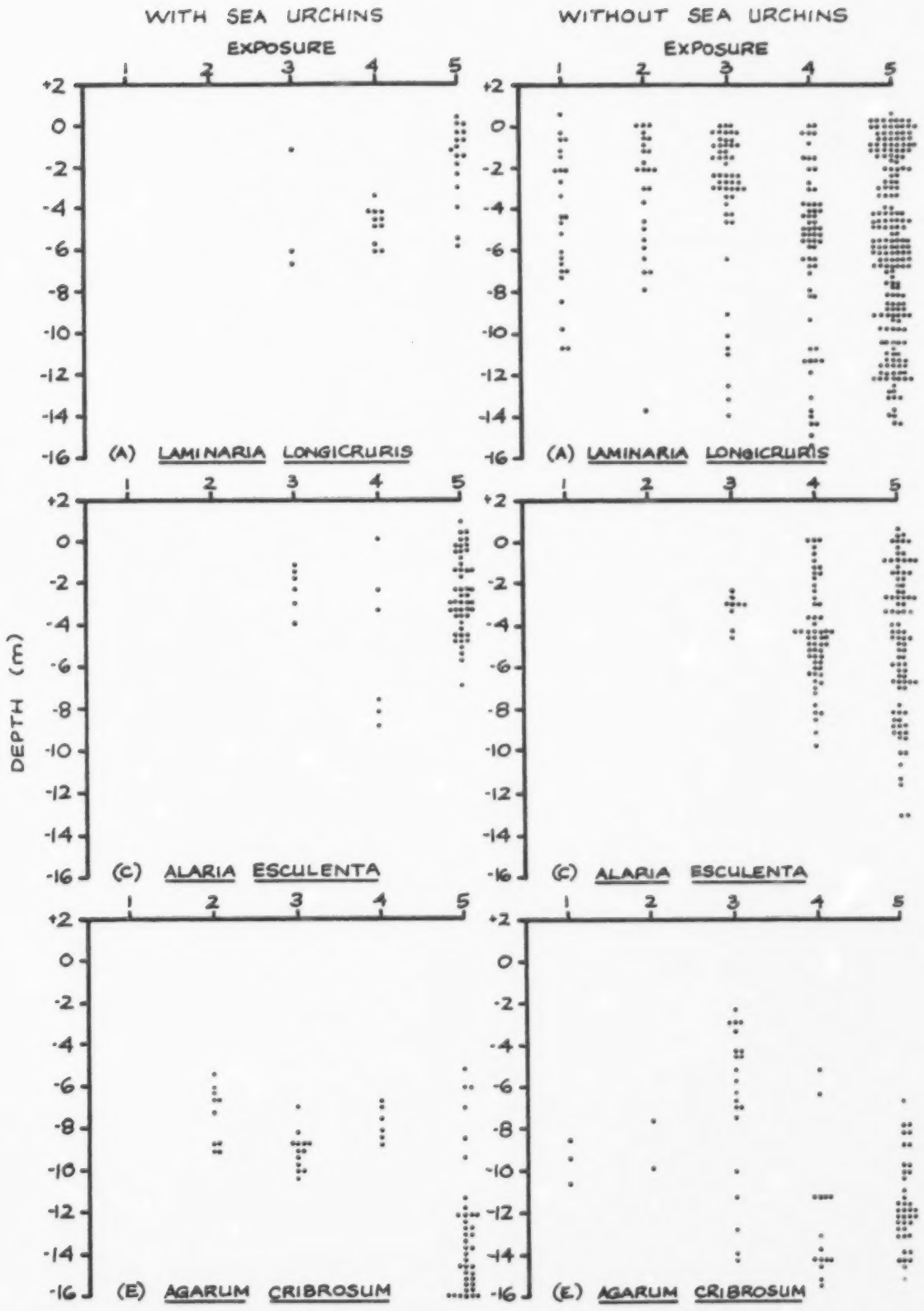
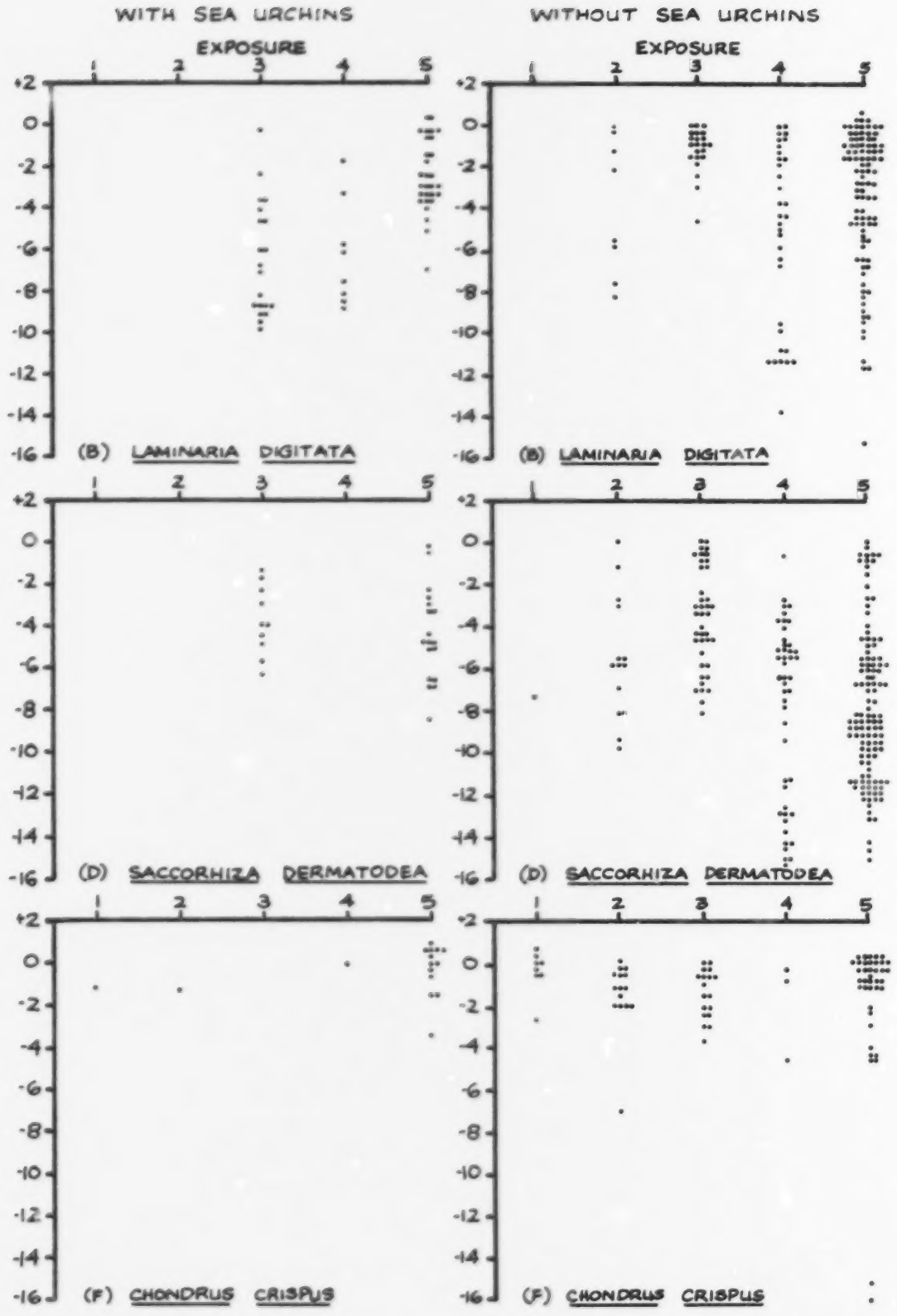


Figure 4. Occurrence of algal groups by exposure index and depth in areas with and without sea urchins.



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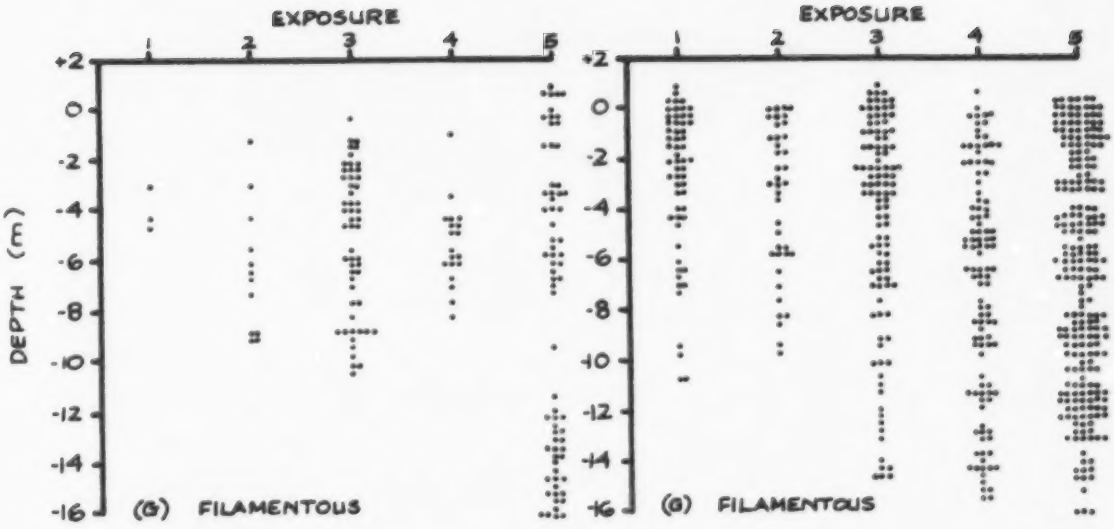

Figure 4. Contd...

Table 7. Percentage occurrence of algae by exposure.

Algae and treatment	Exposure to wave action				
	1	2	3	4	5
With urchins:					
Laminaria longicruris	0	0	4	12	11
L. digitata	0	0	29	9	18
Alaria	0	0	9	6	33
Saccorhiza	0	0	15	0	12
Agarum	0	31	19	6	26
Filamentous	33	20	79	20	49
Moss	4	2	0	1	9
Without urchins:					
L. longicruris	50	49	46	49	71
L. digitata	0	16	19	27	34
Alaria	0	0	8	45	32
Saccorhiza	2	27	40	36	42
Agarum	6	4	18	12	14
Filamentous	68	65	99	92	80
Moss	13	23	14	6	13
Without urchins since 1980:					
L. longicruris	-	-	-	100	86
L. digitata	-	-	-	53	71
Alaria	-	-	-	24	43
Saccorhiza	-	-	-	12	0
Agarum	-	-	-	12	14
Filamentous	-	-	-	76	86
Moss	-	-	-	12	0

Table 8. Number of stations occupied at each exposure with and without sea urchins.

	Exposure					Total
	1	2	3	4	5	
With sea urchins	26	61	68	93	141	389
Without sea urchins	70	51	117	128	289	655

Table 9. Differences between algal occurrence with and without urchins from chi-square contingency tables.

Algae	Exposure				
	1	2	3	4	5
Laminaria longicruris	P<0.01[a]	P<0.01[a]	P<0.01[a]	P<0.01	P<0.01
L. digitata	b	b	P>0.05	P<0.01	P<0.01
Alaria	b	b	P>0.05	P<0.01	P>0.05
Saccorhiza	b	P<0.01[a]	P<0.01	P<0.01[a]	P<0.01
Agarum	b	P<0.01[a]	P>0.05	P>0.05	P>0.05
Chondrus	P>0.05	P<0.01[a]	P<0.01[a]	P>0.05	P>0.05
Filamentous	P<0.01	P<0.01	P<0.01	P<0.01	P<0.01

[a]There was an obvious difference, but it was not testable with chi-square because one variable had less than five observations.
[b]There was not an obvious difference, and there were not enough observations to test for a difference with chi-square.

In the presence of sea urchins L. longicruris occurred only in shallow water (≤ 6 m) and in the most exposed locations. However, even in Exposures 4 and 5 it occurred at only 12% and 11% of the stations respectively. In the absence of sea urchins it increased significantly in all exposures and spread throughout the depth range surveyed. On the transects where urchins had been absent for two years it approached 100% occurrence.

L. digitata was found in the more exposed and shallow stations both with and without urchins but expanded its depth and exposure range in the absence of sea urchins. It increased significantly in Exposures 4 and 5 by one year after sea urchin mortality, but recovery was greater after two years.

A. esculenta was even more restricted to exposed areas than L. digitata, being found almost exclusively in Exposure 5 in areas with urchins and increasing only in Exposure 4 in their absence.

The expansion of S. dermatodea, in both depth and exposure, after the mortality of sea urchins was nearly as dramatic as the expansion of L. longicruris. Its increase in occurrence was statistically significant ($P < 0.01$) in all but the most sheltered sites. Among the kelps its frequency of occurrence was second only to L. longicruris. S. dermatodea, an early colonizing annual, was again rare on transects where there had not been urchins for two years.

A. cribrosum distribution and frequency of occurrence were similar under all three conditions except for Exposure 2 where it showed an obvious decrease in the absence of urchins.

The C. crispus category also included small amounts of Phyllophora sp. deeper than ca. 3 m. C. crispus is a shallow-water species confined to the most exposed transects in the presence of sea urchins. It expanded significantly in Exposures 2 and 3 and was found a little deeper in the absence of urchins.

Filamentous algae was the most ubiquitous, occurring throughout the depth range at all exposures. It occurred at greater than 90% of the stations for three of the exposures without sea urchins and increased significantly in all exposures; however, its biomass would be small compared to kelp biomass.

HABITAT OF SMALL JUVENILE LOBSTERS

A crude estimate of lobster nursery area (Table 10) shows that it is almost equally distributed among exposure categories, but includes a decreasing percentage of each area with increasing exposure. The total nursery area was estimated at 14% of the total survey area suitable for seaweed and sea urchins.

Table 10. Habitat area for small juvenile lobsters.

	Exposure					Total
	1	2	3	4	5	
Habitat area (km^2)	9	14	13	15	19	70
Percentage of area at each exposure	57	46	28	13	6	

DISCUSSION

Only about one-half the coastline length from Ship Harbour to Cape Sable Island was suitable habitat for subtidal seaweeds and sea urchins. Of this, only one-half was in the most exposed locations (Exposures 4 and 5), yet over 80% of the habitat area was found adjacent to these exposed shores.

Exposed seaweed beds are not well studied in Nova Scotia due to the difficulties of working in high wave surge. One study (Gerard and Mann, 1979) found that the production/biomass ratio of L. longicruris was 70% higher in a sheltered than an exposed site, but the biomass was higher on the exposed site. They concluded that the morphological adaptations L. longicruris made to survive in high wave surge were responsible for the lower P/B ratio. However, as demonstrated by Wheeler (1980) for Macrocystis pyrifera, low water motion can also be limiting to kelp growth.

Sea urchins were absent or nearly absent on all transects west of Gaetz Head to Medway Harbour and absent on four of seven transects from Gaetz Head east to Ship Harbour. This was the same pattern reported from the less extensive survey of Miller and Colodey (1983). The estimate of urchins destroyed in this area is about 30% greater, however, than that given by Miller and Colodey due mainly to the revised value for habitat width. It is estimated, using the same value for live weight of urchins/m^2, that 109,000 t (live weight) of sea urchins have died between Ship Harbour and Medway Harbour.

The outbreak of sea urchin disease from Medway Harbour to Barrington Bay occurred in October, as did the outbreak in the Halifax area in 1980. It did not cause complete mortalities over large stretches of coastline, as did the outbreak which started in late August 1981.

On the eastern shore from Ship Harbour to Canso, outbreaks of disease have caused similar accumulations of tests from dead sea urchins in 1981 and 1982. The percentages of urchins destroyed during these disease outbreaks are not known, but lobster fishermen in the area report a decrease in the numbers of urchins caught in their traps after the 1981 outbreak.

Depth distributions for algal groupings were similar to those reported by Edelstein et al. (1969) and Mann (1972a).

When exposure and depth distribution were examined it was found that most algal groups extended into deeper water in exposed areas. This was mostly due to hard substrate extending into deeper water in exposed areas, providing a suitable growing surface.

Chapman (1979) described the normal sequence of algal colonization as proceeding from diatoms to fast-growing algae to larger algae. Our data were collected from formerly barren

areas 8-12 months and sometimes 20-22 months after mass mortalities of the sea urchins. Recolonization was proceeding rapidly with filamentous algae, L. longicruris and S. dermatodea respectively, increasing most in occurrence in the first 8-12 months. On the two transects in their second year of recolonization increases in occurrence since the first year were greatest in L. longicruris, L. digitata, and filamentous algae respectively. Therefore, we can see that Laminaria sp., large, long-lived kelps, had begun to recolonize in the first year and dominated the regrowth in the second year. Saccorhiza, a fast-growing annual, had been largely displaced by the second year of regrowth.

Breen and Mann (1976) found the same sequence of algal recolonization over an 18 month period following an experimental urchin removal. Other authors, Paine and Vadas (1969) and Kain (1975), working on the west coast of North America and the Atlantic coast of Europe, respectively, described similar sequences of recolonization ending in a community dominated by Laminaria sp.

Estimates of the length of time for recolonized areas to reach plant biomass levels of mature kelp beds vary. Breen and Mann (1976) found it was reached in 18 months, while Kain (1975) found that it took three years in the shallowest subtidal sites and longer in deeper ones. Several factors probably contribute to the rate of regrowth. These would include depth (Kain, 1976), illumination (Gerard and Mann, 1979), and nutrients (Gagne and Mann, 1981). Although samples for biomass determinations were not collected, it was observed that a mature kelp forest has not yet grown along most of the coastline in the urchin die-off area.

Among the transects with urchins present, approximately 70% had either no Agarum or Agarum with Laminaria, while less than 10% had Agarum only (Table 11). This agrees with Tremblay's and Chapman's (1980) argument that in the absence of Laminaria, Agarum does not survive in areas dominated by sea urchins. In areas without urchins it is too early to tell if Agarum will be out competed and eliminated by the Laminaria sp., although Agarum did decrease in occurrence in one exposure category.

ACKNOWLEDGEMENTS

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Table 11. Occurrences of *Agarum* in relation to *Laminaria* sp. and sea urchins by transect.

	Number of transects	*Laminaria* and *Agarum*	*Laminaria* only	*Agarum* only	Both absent
Urchins present	31	12	7	3	9
Urchins absent	50	24	19	1	6
Totals:	81	36	26	4	15

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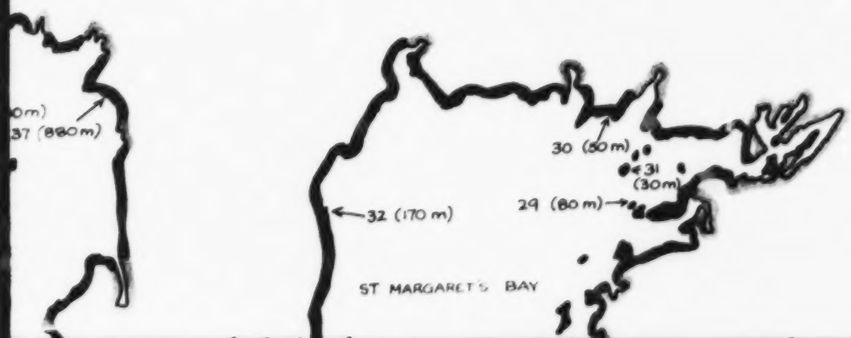
KEY

Shoreline adjacent to sea bottom suitable for macrophytes and sea urchins (hard bottom)

Shoreline adjacent to sea bottom unsuitable for macrophytes and sea urchins (soft bottom)

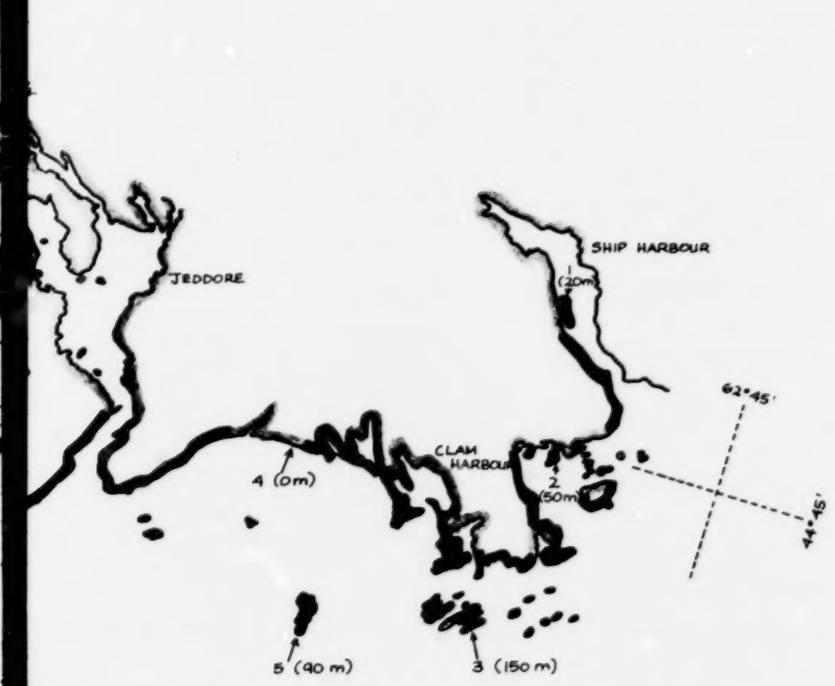
← Transect number (length in meters)

PORT HEBERT
PORT JOLI
64 (30 m)
PORT MOUTON
66 (2200 m)
65 (770 m)
67 (200 m)
68 (70 m)


37 (880 m)
30 (50 m)
31 (30 m)
29 (80 m)
32 (170 m)
ST MARGARET'S BAY

C

63°30'
44°45'
13 (180m)
BEDFORD BASIN
14 (20m)
15 (0m)
NORTHWEST ARM
12 (80 m)
HALIFAX HBR.
11 (40m)
COLE HARBOUR
LAWRENCETOWN
9 (70 m)
COW BAY
10 (700 m)
8 (270 m)
CHEZZETCOOK INLET
7 (50 m)
PETPESWICK INLET
MUSQUODOBOIT HARBOUR
6 (1800m)
16 (60 m)
63°45'
44°30'
19 (50m)
PENNANT BAY
18 (230m)
SAMBRO HBR.


JEDDORE
SHIP HARBOUR
1
(20m)
62°45'
CLAM HARBOUR
2
(50m)
44°45'
4 (0m)
5 (90 m)
3 (150 m)

KEY

Shoreline adjacent to sea bottom suitable for macrophytes and sea urchins (hard bottom)

Shoreline adjacent to sea bottom unsuitable for macrophytes and sea urchins (soft bottom)

← Transect number (length in meters)

Areas of shoreline surveyed

SCALE 1:150,000

B

MEDWAY RIVER

MERSEY RIVER

64°45'

44°00'

62 (50 m)

61 (420 m)

63 (400 m)

LIVERPOOL BAY

60 (310 m)

MEDWAY HBR.

58 (300m)

59 (120 m)

57 (160 m)

44°15'

64°30'

LA HAVE RIVER

56 (30 m)

GREEN BAY

55 (1200 m)

54 (320 m)

63 (140 m)

51 (0 m)

50 (410 m)

52 (220 m)

LUNENBURG BAY

48 (370 m)

49 (50 m)

ROSE BAY

47 (930 m)

46 (430 m)

35 (520 m)

36 (34

40 (70 m)

39 (50

42 (0m)

41 (90 m)

MAHONE HARBOUR

44 (0 m)

MAHONE BAY

45 (0m)

43 (0m)

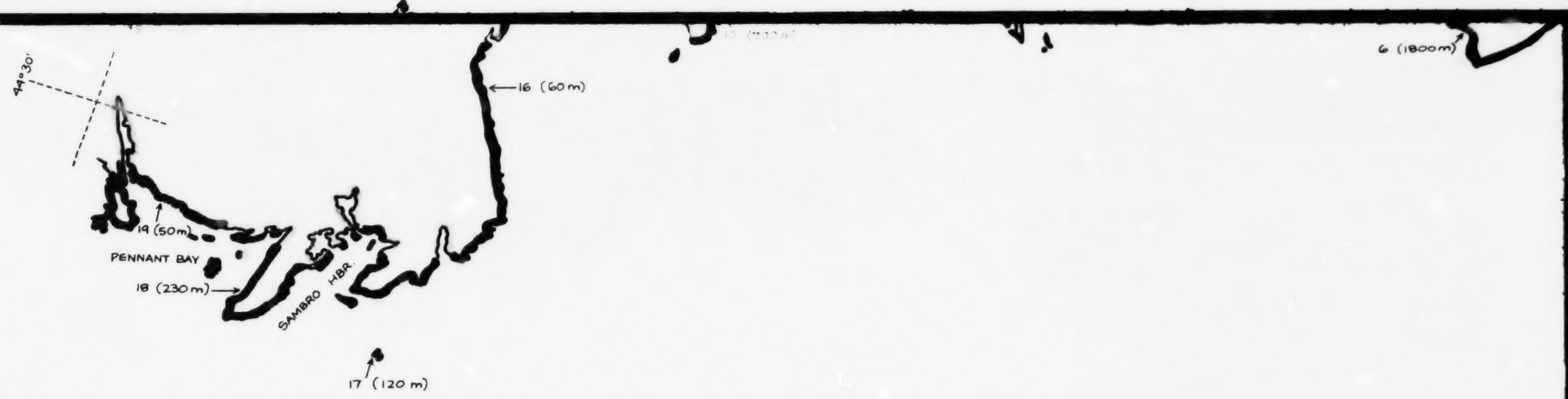
66°

44°

NOVA

A

(130m)
37 (880m)
30 (50m)
31 (30m)
29 (80m)
32 (170 m)
ST. MARGARET'S BAY
28 (0m)
33 (190m)
34 (400 m)
27 (160 m)
PEGGY'S COVE
BLIND BAY
26 (320 m)
G (70m)
SHAG BAY
F (70m)
E (160m)
PROSPECT BAY
C (30m)
B (0m)
D (410 m)
A (370 m)
63°45
44°30
62°
45°
ATLANTIC OCEAN



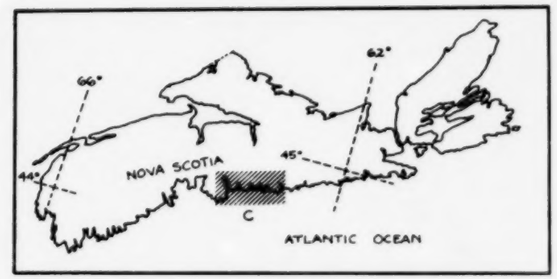
KEY

Shoreline adjacent to sea bottom suitable for macrophytes and sea urchins (hard bottom)

Shoreline adjacent to sea bottom unsuitable for macrophytes and sea urchins (soft bottom)

Transect number (length in meters)

Areas of shoreline surveyed



SCALE 1 150,000

5 (90 m)

3 (30 m)

POOR

QUALITY

ORIGINAL